U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

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DETERMINATION OF EFFECTS OF AMBIENT CONDITIONS ON AIRCRAFT ENGINE EMISSIONS ENGINE TESTING - GTCP 85 APU, TPE 331 TURBOPROP. VOLUME 1

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

MARCH 1976

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PB 252 825

DETERMINATION OF EFFECTS OF AMBIENT CONDITIONS ON AIRCRAFT ENGINE EMISSIONS

ENGINE TESTING - GTCP 85 APU, TPE 331 TURBOPROP

VOLUME 1

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

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16. ABSTRACT

Under Environmental Protection Agency contract number 58-03-2156, AiResearch Manufacturing Company of Arizona, a Division of the Garrett Corporation, conducted full scale engine tests on a GTCP85-98CK Auxiliary Power Unit and a TPE331-5-251M Turboprop engine. The purpose of this program was to measure exhaust emission of HC, CO, CO_2, NO_x, and smoke at controlled (temperature, humidity, and pressure) engine inlet conditions. This data along with other available data will provide the data base for the determination of the effects of ambient conditions on gas turbine engines.

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DETERMINATION OF EFFECTS OF AMBIENT CONDITIONS ON AIRCRAFT ENGINE EMISSIONS ENGINE TESTING - GTCP 85 APU, TPE 331 TURBOPROP

VOLUME 1

by

G.A. Slogar

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A Division of The Garrett Corporation
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Phoenix, Arizona 85034

Contract No. 68-03-2156

EPA Project Officer: Gary Austin

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

March 1976

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This report was furnished to the Environmental Protection Agency by AiResearch Manufacturing Company of Arizona, Phoenix, Arizona 85034, in fulfillment of Contract No. 68-03-2156. The contents of this report are reproduced herein as received from AiResearch Manufacturing Company of Arizona. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

Publication No. EPA-460/3-76-009-a

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ACKNOWLEDGMENTS

This report was prepared by the AiResearch Manufacturing Company of Arizona, A Division of The Garrett Corporation, under EPA Contract Number 68-03-2156.

The program period of performance was December 20, 1974 through December 20, 1975, and the AiResearch Project Engineer was Peter E. Matuschak. Gerrick A. Slogar was the Principal Investigator and was responsible for all engine tests and emissions data acquisition.

All tests with GTCP85 and TPE331 Engines were run at the AiResearch Test Facilities in Phoenix, Arizona. Processed data was transmitted to Paul Donovan of Calspan Corporation for statistical analysis. H. T. McAdams of Calspan, and Erin L. Peterson of AiResearch, assisted in establishing data handling procedures that allowed taped data to be transferred between AiResearch CDC 6400 and Calspan IBM 370/168 computers.

The EPA Project Officer was Gary Austin. His technical direction and assistance during the program provided significant contribution.

BRITISH ENGINEERING TO INTERNATIONAL SYSTEM OF UNITS (SI) CONVERSION FACTORS

Power	$0.7457 \frac{\text{kw}}{\text{hp}}$
Torque	$1.356 \frac{\text{N.m}}{\text{lb ft}}$
Pressure	$3.3768 \frac{\text{kPa}}{\text{in. Hg (60°F)}}$
	$0.2488 \frac{\text{kP}_\text{a}}{\text{in. H}_2\text{O (60°F)}}$
	$6.895 \frac{\text{kP}_\text{a}}{\text{psi}}$
Flow-rate	$0.4536 \frac{\text{kg/hr}}{\text{lb/hr}}$
	$3.785 \frac{\text{litre/hr}}{\text{gal/hr (U.S. liquid)}}$
Length	$0.3048 \frac{\text{m}}{\text{ft}}$

DETERMINATION OF EFFECTS
OF AMBIENT CONDITIONS
ON AIRCRAFT ENGINE EMISSIONS
ENGINE TESTING -
GTCP85 APU, TPE331 TURBOPROP

1.0 INTRODUCTION AND SUMMARY

1.1 Introduction

The investigation reported herein was performed by AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, to determine the effect of ambient conditions on aircraft engine emissions under Contract 68-03-2156 for the Environmental Protection Agency, Emission Control Technology Division, Ann Arbor, Michigan.

The purpose of this program was to measure exhaust emissions of hydrocarbons, carbon monoxide, smoke, and oxides of nitrogen from an AiResearch Turboprop Engine Model TPE331, and a Gas Turbine Auxiliary Power Unit (APU) GTCP85, when tested under controlled ambient conditions of humidity, temperature, and pressure. Initially the test program was 8 months. A supplemental program was subsequently added to investigate the turboprop engine fuel management system modifications required to meet 1979 EPA aircraft engine emissions standards, and the program was extended to 12 months.

Ultimate application of the data generated in this program will be a specification of correction factors for the effect of ambient conditions on small gas turbine engine exhaust emissions. Definition of these correction factors by Calspan Corporation may eliminate the requirement for controlled-environment testing of a given production engine to determine compliance with the 1979 EPA Aircraft and Aircraft Engine Emissions Standards, after the humidity/emissions relationship is characterized for that particular engine type or model.

Therefore, all data gathered during this program was transmitted to the Calspan Corporation, Buffalo, New York, where the data was subjected to statistical analysis to assist in deriving an empirical correlation between variations in ambient conditions and exhaust emissions for each candidate test engine.

1.2 Summary

AiResearch completed all emissions measurements for the production gas turbine engines specified in Table 1-1, over the combination of controlled ambient test conditions, specified in Table 1-2. The exact power conditions tested for each gas turbine engine was controlled by operating temperature limitations that were dependent on engine inlet ambient conditions. The resultant computer output data reduction runs obtained during this program is presented in Volume 2 of this report.

TABLE 1-1

Engine Type	Engine Model	Maximum Power Level	Pressure Ratio
Turboprop	TPE331-3U-303 TPE331-5-251M	626 kw (840 shp)	10.6
APU	GTCP85-98CK	216 kw (290 eshp)	3.6

Testing was conducted chronologically as follows:

(a) GTCP85-98CK APU engine testing

(b) TPE331-3U-303 turboprop combustor rig testing

    (1) To verify 840 shp/$\sqrt{\theta}\delta$ engine maximum rated condition compliance to the EPA 1979 Aircraft Engine Emissions Standards using primary fuel atomizers only during engine idle operation

(2) To compare combustor performance using normal TPE331 fuel delivery system (5 primary and 10 secondary fuel atomizers sequenced and activated) and "primary fuel atomizer only" operation

(3) To verify satisfactory combustor performance at a $706 \text{ shp}/\sqrt{\theta\delta}$ maximum derated power condition with secondary atomizers activated over the range of 7 engine load conditions to ensure safe subsequent engine testing

(4) Repeat of (3) above without secondary fuel atomizers

(c) TPE331 turboprop engine testing

The emissions data generated during this program was transmitted to the Calspan Corporation, Buffalo, New York, in a format suitable for statistical analysis. AiResearch performed no statistical analytical work on the data other than verifying that the data contained no errors.

Photographs of the two production engine types used during this program are shown in Figure 1-1.

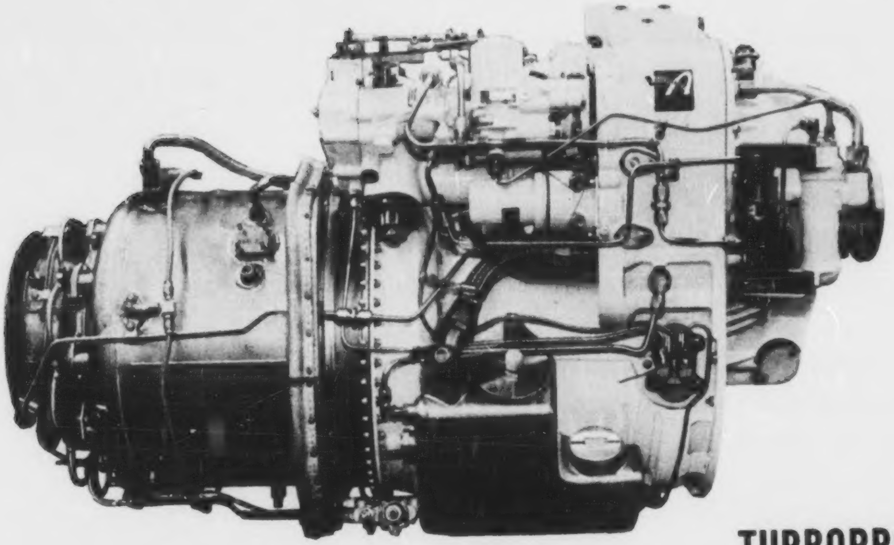
The engine inlet ambient test conditions for both of the engines are shown in Table 1-2.

Turboprop engine emissions, for each engine inlet ambient condition, were measured for gaseous and particulate emissions of the following range of representative power settings:

TABLE 1-2

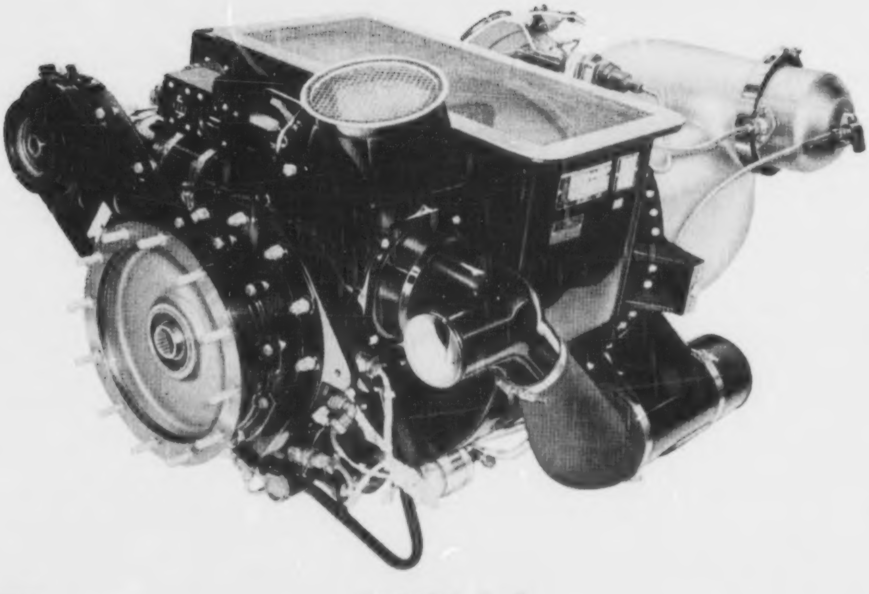
AMBIENT TEST CONDITIONS

<table>
<tr><th rowspan="2">Test Point</th><th colspan="2">Temperature</th><th colspan="2">Humidity</th><th colspan="2">Barometric Pressure</th></tr>
<tr><th>°C</th><th>°F</th><th>Grams H_2O/ Kilogram Air</th><th>Grains H_2O/ Pound Air</th><th>Mm Hg</th><th>Inches Hg</th></tr>
<tr><td>1</td><td>-7.0</td><td>19</td><td>1.0</td><td>7.0</td><td colspan="2" rowspan="12">↑ ↑
Hold constant at standard condition as specified in the United States Standard Atmosphere, 1962 for the test cell altitude.</td></tr>
<tr><td>2</td><td>-7.0</td><td>19</td><td>2.0</td><td>14.0</td></tr>
<tr><td>3</td><td>4.0</td><td>39</td><td>2.0</td><td>14.0</td></tr>
<tr><td>4</td><td>4.0</td><td>39</td><td>5.0</td><td>35.0</td></tr>
<tr><td>5</td><td>15.0</td><td>59</td><td>2.0</td><td>14.0</td></tr>
<tr><td>6</td><td>15.0</td><td>59</td><td>5.0</td><td>35.0</td></tr>
<tr><td>7</td><td>15.0</td><td>59</td><td>7.5</td><td>52.5</td></tr>
<tr><td>8</td><td>15.0</td><td>59</td><td>10.0</td><td>70.0</td></tr>
<tr><td>9</td><td>33.0</td><td>91</td><td>10.0</td><td>70.0</td></tr>
<tr><td>10</td><td>33.0</td><td>91</td><td>15.0</td><td>105.0</td></tr>
<tr><td>11</td><td>33.0</td><td>91</td><td>20.0</td><td>140.0</td></tr>
<tr><td>12</td><td>33.0</td><td>91</td><td>25.0</td><td>175.0</td></tr>
<tr><td>13</td><td>15.0</td><td>59</td><td>7.5</td><td>52.5</td><td>580</td><td>22.83</td></tr>
<tr><td>14</td><td>15.0</td><td>59</td><td>7.5</td><td>52.5</td><td>650</td><td>25.98</td></tr>
<tr><td>15</td><td>15.0</td><td>59</td><td>7.5</td><td>52.5</td><td>740</td><td>29.13</td></tr>
<tr><td>16</td><td>15.0</td><td>59</td><td>7.5</td><td>52.5</td><td>500</td><td>19.69</td></tr>
</table>



TURBOPROP

TPE331



85 SERIES

MP-42517

FIGURE 1-1

(a) Idle (5-percent power)
(b) 1.5 times idle
(c) 2.0 times idle
(d) Climb-out (90-percent power)
(e) Approach (30-percent power)
(f) Take-off (100-percent power)
(g) Cruise-intermediate (70-percent power)

APU engine emissions, for each engine inlet ambient condition, were measured for gaseous and particulate emissions over the following range of representative power settings:

(a) Idle
(b) Shaft power only
(c) Rated shaft power
(d) Bleed-air load only
(e) Combination load

Combustion rig testing, of an idle operation mode, where only the primary fuel atomizers are employed, indicated this system would enable the turboprop engine to meet 1979 aircraft engine emissions standards without adversely affecting engine performance and service life parameters.

2.0 TEST ENGINES DESCRIPTION

The GTCP85 Series pneumatic and shaft power gas turbine engine is designed for ground and on-board aircraft auxiliary power. The single-shaft engine provides mechanical shaft power driving aircraft accessories such as an alternator when airborne, provides pneumatic bleed-air power for starting main aircraft engines and for aircraft cabin air-conditioning when on the ground, and provides cooling air for engine lubricating oil and for the engine enclosure at all times. Typical aircraft applications for the 85 Series APUs include the Boeing 727 and 737 and the Douglas DC-9 commercial jetliners.

Physical and operational characteristics of the GTCP85 series pneumatic and shaft power gas turbine engine are listed in the specification data sheet following this section.

The TPE331 series turboprop is a single-shaft gas turbine engine that operates at essentially constant rotor speed over a range of flight power settings. At ground idle and taxi, however, operation is reduced to 65 percent of rated engine speed to minimize noise and fuel consumption. Taxi-idle power is 5 percent of the takeoff rating. Accordingly, for purposes of this emission measurement program the; idle, 1.5 times idle, and 2 times idle, test conditions were performed at 65 percent rated engine rpm. All other power settings were operated at 100 percent rated speed. In conformance with EPA emission standards for P2 Class (turboprop) aircraft engines, the power settings for approach, climbout, and takeoff, are at 30, 90 and 100 percent of rated shaft horsepower. The turboprop engine cruise condition is limited by exhaust gas temperature and varies as a function of altitude, ambient temperature, and flight speed. As related to static test conditions, cruise power would be 85 percent of the takeoff-power rating. An intermediate power setting of approximately 70 percent of rated takeoff-power was selected as the cruise operating condition. The normal cruise setting is only 5 percent less power than climbout and the intermediate power setting provided a more favorable test point distribution for data interpolation.

The TPE331 is the prime propulsion engine for business aircraft such as the Turbo Commander 690, and Swearingen Metro Liner. Physical and operational characteristics of the TPE331 series turboprop engine are listed in the Specification Data Sheet at the end of this section.

2.1 Candidate Combustion System

Test engines utilized in this program employ two different combustion systems. The two combustor types are illustrated in Figure 2-1. The APU combustion system consists of a single-can combustor with a dual orifice fuel injector, oriented tangentially relative to the engine axis. This is a typical combustor configuration for the 200-350 eshp size APU.

The turboprop combustor system, commonly used for engines in the 500 to 1000 eshp range, is a reverse-flow annular configuration. The fuel injection system is composed of 5 radial start and 10 axial main simplex fuel injectors staged through a single flow divider.

These variations in combustor aerodynamics and fuel introduction are reflected in resulting experimental data and typify a broad range of applications.

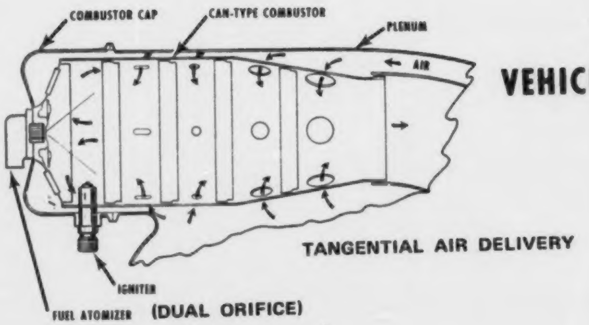
2.2 Engine Models Compared with 1979 Emissions Standards

Table 2-1 illustrates current emission levels of the engines tested under this program. The table shows that neither engine currently meets Federal Standards. The turboprop engine, however, has demonstrated the capability of meeting 1979 Standards, with minor modifications. Operation of the TPE331 at idle on primary atomizers alone will reduce the carbon monoxide and hydrocarbon emissions sufficiently to allow compliance as shown in Figure 2-2. During this emissions measurement program the TPE331 was tested in this manner to determine whether variations in ambient conditions will reflect emission levels equal to or less than specified standards.

GTCP85 SERIES

CAN-TYPE COMBUSTOR

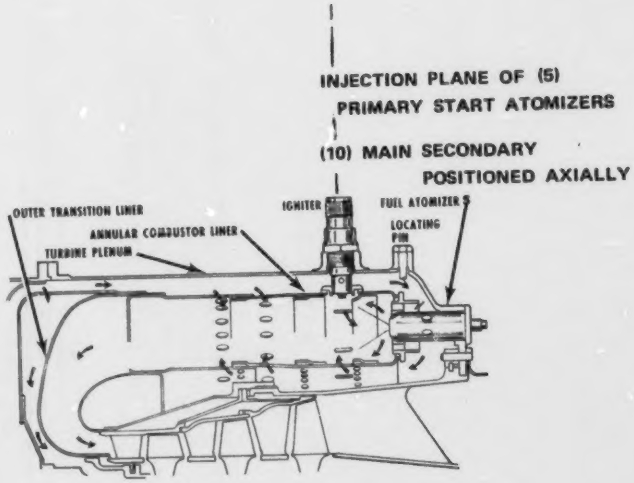
VEHICULAR, AIRCRAFT APU AND INDUSTRIAL GAS TURBINES


COMBUSTOR CAP
CAN-TYPE COMBUSTOR
PLENUM
AIR
TANGENTIAL AIR DELIVERY
IGNITER
FUEL ATOMIZER (DUAL ORIFICE)

TPE331 SERIES

REVERSE-FLOW ANNULAR COMBUSTOR

INDUSTRIAL, MARINE, AIRCRAFT PROPULSION AND APU


INJECTION PLANE OF (5) PRIMARY START ATOMIZERS
(10) MAIN SECONDARY POSITIONED AXIALLY
OUTER TRANSITION LINER
ANNULAR COMBUSTOR LINER
TURBINE PLENUM
IGNITER
FUEL ATOMIZERS
LOCATING PIN

CANDIDATE AIRESEARCH COMBUSTION SYSTEMS

FIGURE 2-1

TABLE 2-1

COMPARISON OF CANDIDATE ENGINE MODEL EXHAUST EMISSIONS WITH 1979 AIRCRAFT AND AIRCRAFT ENGINE EMISSION STANDARDS

TPE331 - Turboprop Class P2

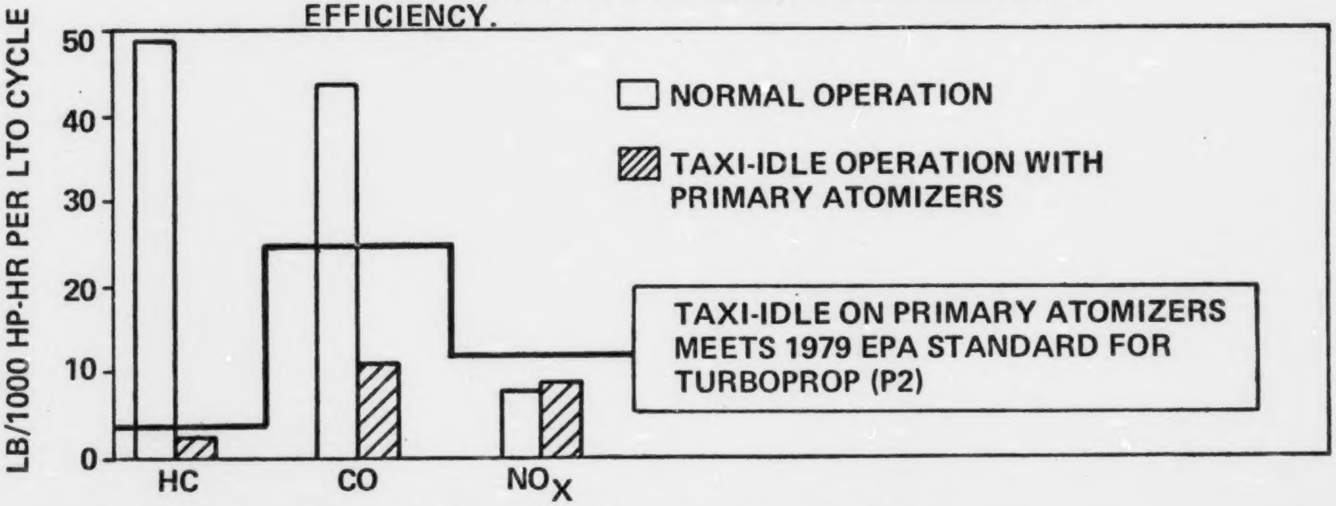
	Units	HC	CO	NO_X	Smoke Number
1979 Standard	LB/1000 HP-HR/LTO	4.9	26.8	12.9	46-50
Current Production		39-103	34-58	6.2-9.9	15-25

GTCP85 APU

	Units	HC	CO	NO_X	Smoke Number
1979 Standard	LB/1000 HP-HR	0.4	5.0	3.0	None
Current Production		0.1-0.6	6.7-8.5	5.4-6.2	

- TPE331-5-251 TURBOPROP (CLASS P2)
- TAXI-IDLE AT 5 PERCENT RATED TAKE-OFF POWER AND 65 PERCENT RATED RPM

NOTE: ALSO RESULTS IN A 5 PERCENT DECREASE IN FUEL CONSUMPTION OVER LTO CYCLE DUE TO IMPROVED EFFICIENCY.

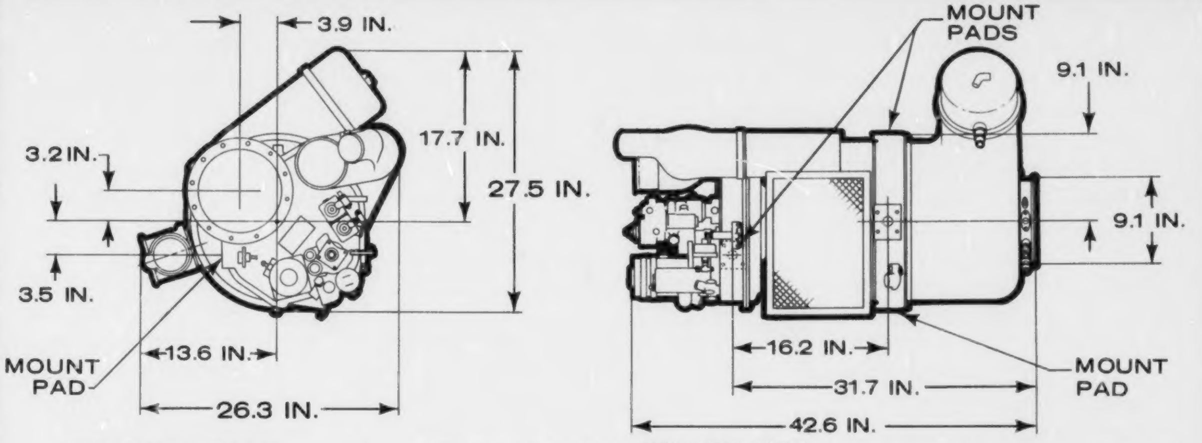


EFFECT OF OPERATION ON PRIMARY ATOMIZERS
DURING TAXI-IDLE
FIGURE 2-2

GAS TURBINE SPEC DATA

MODEL GTCP85-98CK

8-1-71 ISSUED



ENVELOPE DATA /

Weight: (INCLUDES ACCESSORIES) 281 LBS MAX (DRY)

Exhaust Area: 53.1 SQ. IN.

Inlet Area: 9.4 IN. × 14.9 IN. = 140.1 SQ. IN.

PERFORMANCE DATA AND LEADING PARTICULARS:

FUELS: MIL-T-5624, JP-4 & JP-5; D1655-66T, TYPES A, B, & A-1

OILS: MIL-L-7808, MIL-L-23699, AND OTHER AIRESEARCH APPROVED LUBRICANTS PER REPORT GT-7800-R

OUTPUT PAD(S): AND20006, TYPE XVI-B

DIRECTION OF ROTATION: CW (FACING PAD) 6,000 RPM

RATED EGT: 1150°F

ROTOR SPEED: 40,700 RPM (FULL LOAD)

RATING: (FOR INDICATED APPLICATION)

AMBIENT COND.: 100°F SEA LEVEL

BLD. AIR FLOW:
(1) 128 LB PER MIN
(2) 111 LB PER MIN
(3) 91 LB PER MIN

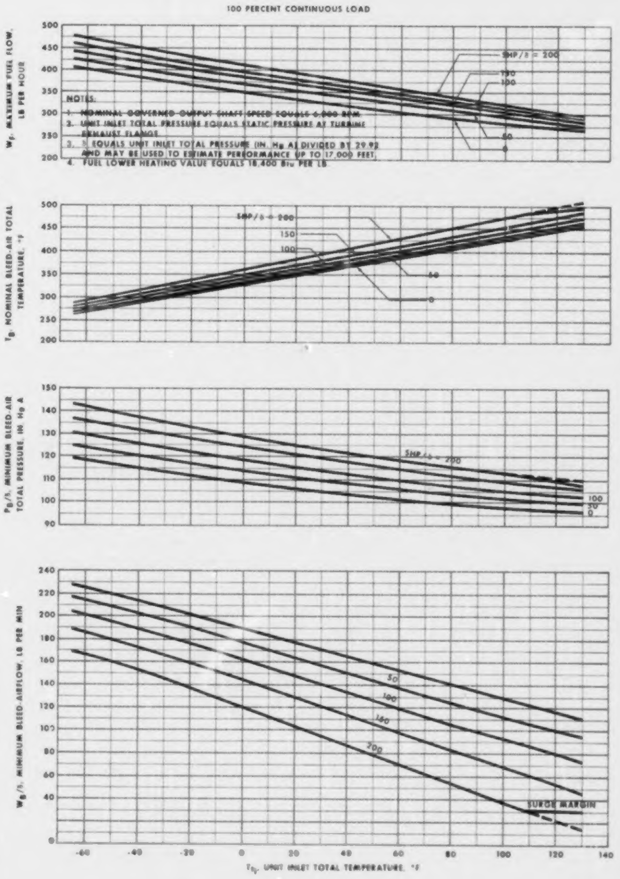
TEMP:
(1) 428 ± 25°F
(2) 434 ± 25°F
(3) 443 ± 25°F

PRESS.:
(1) 96.7 IN.Hg ABS
(2) 101.4 IN.Hg ABS
(3) 105.9 IN. Hgs ABS

PRESS. RATIO:

SHAFT HP:
(1) ZERO
(2) 50
(3) 100

COMBINATION LOAD: SEE RATINGS ABOVE



SPECIFICATION DATA:

INSTALLATION DRWG: 380678-1-2

MODEL SPEC.: SC-6011A

BASIC SPEC: FAA TSO-C77. CAT. II CLASS C AND MIL-P-8686

APPLICATION: BOEING 727-200

GARRETT AIRESEARCH MANUFACTURING COMPANY OF ARIZONA, 402 SOUTH 36TH ST. , PHOENIX, ARIZONA
MS 1406-46

GTCP 85-98CK

STANDARD FEATURES:

- TWO-STAGE CENTRIFUGAL COMPRESSOR
- SINGLE-STAGE RADIAL INFLOW TURBINE
- AUTOMATIC CONTROL SYSTEM
- OVERSPEED SHUTDOWN PROVISIONS
- TURBINE WHEEL CONTAINMENT
- SPEED CONTROL WITHIN ±0.5% AT ANY STEADY-STATE CONDITION WITHIN 1.0 SECONDS AFTER LOAD CHANGE
- SPEED CONTROL WITHIN 1.5% FROM NO-LOAD TO FULL LOAD AND FROM FULL LOAD TO NO-LOAD
- DRY-SUMP OIL SCAVENGE SYSTEM
- PROVISIONS FOR OIL AND FUEL PRESSURE SENSING LINES
- COOLING AIR AVAILABLE FOR DRIVEN EQUIPMENT
- SHAFT POWER OUTPUT PRIORITY
- ACCELERATION LIMITING CONTROL
- EXHAUST OVERTEMPERATURE CONTROL
- TACHOMETER OUTPUT DRIVE PAD
- PROVIDES EGT SIGNAL
- PROVIDES OIL TEMPERATURE SIGNAL
- SINGLE CAN COMBUSTOR
- OPERATING ATTITUDE: ZERO TO 20-DEGREES POSITIVE OR NEGATIVE DISPLACEMENT TO EITHER SIDE WITH 10-DEGREES POSITIVE OR NEGATIVE DISPLACEMENT OF THE FORE-AND-AFT AXIS ,OR

  ZERO TO 20-DEGREES POSITIVE OR NEGATIVE DISPLACEMENT OF THE FORE-AND-AFT AXIS WITH 10-DEGREES POSITIVE OR NEGATIVE DISPLACEMENT TO EITHER SIDE

STANDARD ACCESSORIES: (INCLUDED IN UNIT WEIGHT)

- FUEL FILTER, PUMP, CONTROL, AND SOLENOID
- IGNITION PLUG
- OIL PRESSURE SWITCH
- CHROMEL-ALUMEL EGT THERMOCOUPLE
- D-C ELECTRIC STARTER
- OIL FILTER
- CENTRIFUGAL THREE-SPEED SWITCH WITH OVERSPEED SAFETY SWITCH
- HOURMETER
- OIL TEMPERATURE BULB
- OIL PUMP
- OIL COOLER AND COOLING FAN
- SINGLE THERMOSTAT SYSTEM

OPTIONALS:

- OIL TANK
- OIL TANK LINES
- PRIMARY FUEL FILTER
- FINE SPEED CONTROL WITH IN ±0.25% FROM NO-LOAD TO FULL LOAD AND FROM FULL LOAD TO NO-LOAD
- ASPIRATOR DUCT
- BRACKETS FOR CONTROLS
- IGNITION LEAD
- IGNITION COIL
- BLEED AIR LOAD CONTROL VALVE
- AIR PRESSURE REGULATOR

CAN BE ADDED WITHOUT CHANGING THE BASIC ENGINE

CUSTOMER INSTALLATION CONSIDERATIONS:

FUEL REQUIREMENTS:

Pressure — 5-PSI ABOVE TRUE VAPOR PRESSURE TO 20 PSIG MAX

Flow — 300 LB PER HOUR MAX @ 100°F INLET AIR TEMP. & FULL LOAD

ELECTRICAL REQUIREMENTS:

Starting — INFINITE 28 VOLT D-C BUS OR EQUIVALENT

Operation — SAME

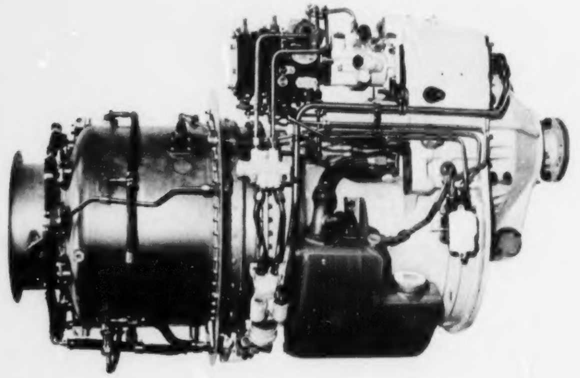
OPERATING ENVIRONMENTS:*

Temperature — COMPRESSOR INLET: MINUS 40°F TO PLUS 130°F
LIMITING ZONE:160°F MAXIMUM SURROUNDING AIR

Altitude — START AND OPERATE TO 14,000 FEET

*INSTALLATION CHARACTERISTICS WILL MODIFY STATED PERFORMANCE

GARRETT/AIRESEARCH
AIRCRAFT ENGINES



TURBOPROP
TPE 331
-251*

ISSUE DATE 1/75

SPECIFICATIONS (STD SEA LEVEL DAY)

CERTIFICATION DATE APRIL 1970

POWER OUTPUT
- **SHAFT H.P.:** 715*
- **THRUST (LBS.):** 152
- **E.S.H.P.:** 776

R.P.M.
- **GAS GEN.:** 41,730
- **SHAFT OUTPUT:** 2000**

ROTATION: CW FROM REAR

S.F.C. (STD. DAY): 0.626 LB/SHP/HR

WEIGHT: 360 LBS.

PRW./WT. RATIO: 1.99

PRESS. RATIO: 10.37

AIRFLOW: 7.75 LB/SEC

T.I.T.: 1840°F

I.T.T. TEMP.: 1693°F

FUEL: JET A, JET B, JET A-1, JP-1, JP-4, JP-5

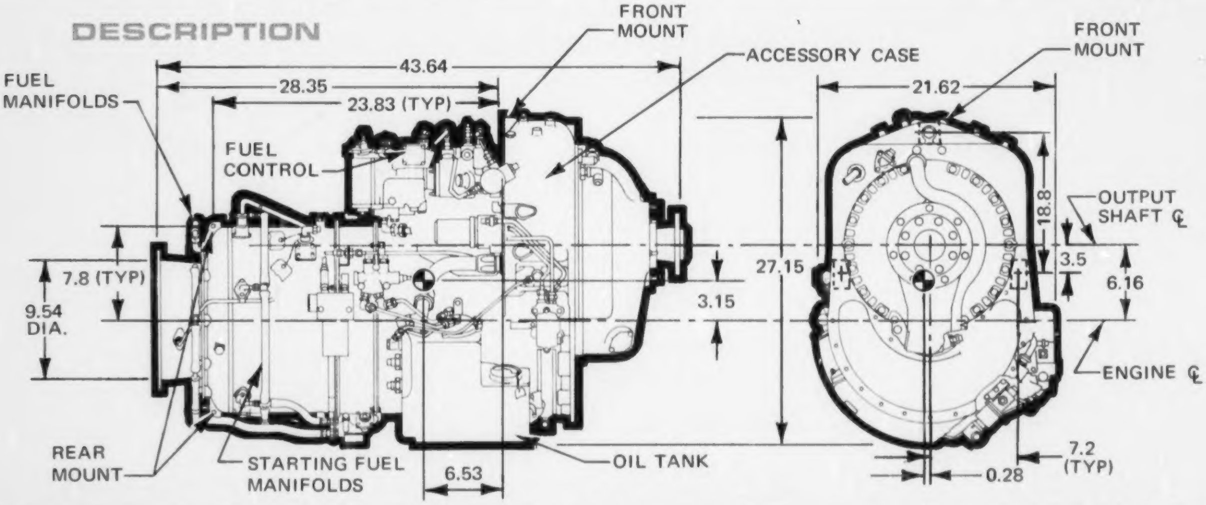
OIL: MIL-L-23699A, MIL-L-7808D, MIL-L-007808F

ELECTRICAL: 24 VDC 16.2 AMP

SPECIFICATION NO.: SC-8006

*THIS ENGINE IS A MATCH-UP OF THE 840 SHP POWER SECTION AND 715 SHP GEAR BOX. THERMODYNAMIC PERFORMANCE; 840 SHP AND 904 ESHP. **OPTIONAL 1591 R.P.M.

DESCRIPTION


FRONT MOUNT
ACCESSORY CASE
FRONT MOUNT
FUEL MANIFOLDS
43.64
28.35
23.83 (TYP)
21.62
FUEL CONTROL
18.8
OUTPUT SHAFT ℄
3.5
6.16
27.15
7.8 (TYP)
9.54 DIA.
3.15
ENGINE ℄
REAR MOUNT
STARTING FUEL MANIFOLDS
6.53
OIL TANK
0.28
7.2 (TYP)

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA 402 S. 36TH ST., P.O. BOX 5217, PHOENIX, ARIZONA 85010
MS 2124-6

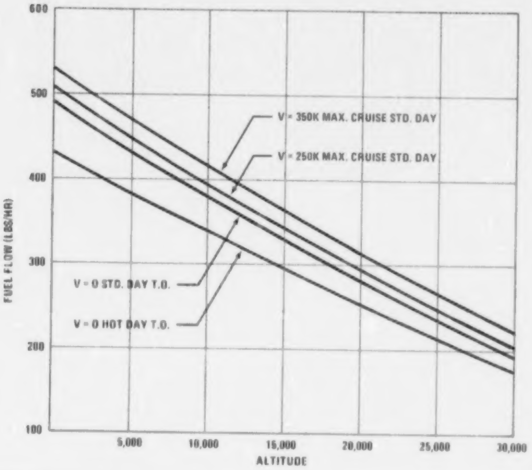
TURBOPROP • TPE 331-251

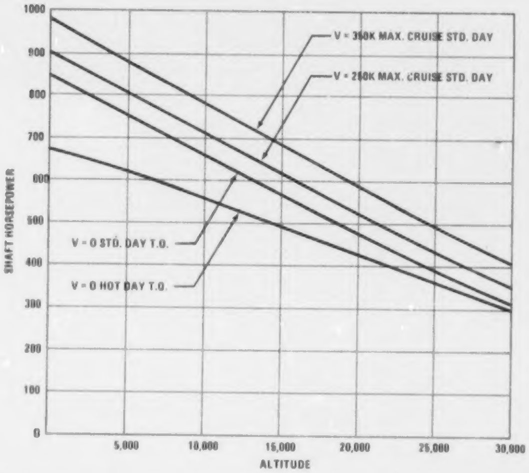
START CAPABILITY: S.L.--20,000 FT.
-40°F +125°F

OPERATIONAL LIMITS: S.L.--35,000 FT.
-65°F +125°F

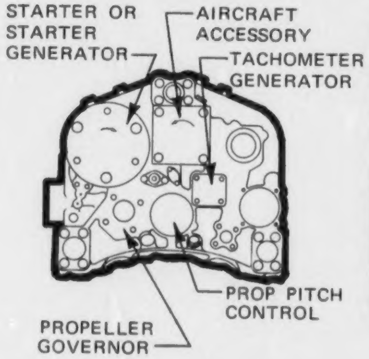
COMPRESSOR BLEED: 10% (MAX.)

PERFORMANCE





ACCESSORY DRIVES & MOUNTING PADS



NOMINAL USE	TYPE OF DRIVE (ONE EACH)	AND DRIVE MODIFICATIONS	ROTATION FACING DRIVE PAD AND R.P.M.	MAXIMUM TORQUE (LB.-IN.)			OVERHUNG MOMENT (LB.-IN.)
				CONTINUOUS	OVERLOAD	STATIC	
AIRCRAFT ACCESSORY	AND20001 TYPE XI-B (MODIFIED)	ROTATION AND R.P.M.	CCW 3959	250	375	1650	125
STARTER OR STARTER-GENERATOR OR ALTERNATOR	AND20002 TYPE XII-D (MODIFIED)	R.P.M., T_c, T_o, AND STUD PATTERN ROTATED 30 DEG.	CW 10,887	300	600	2200	500
TACHOMETER-GENERATOR	AND20005 TYPE XV-B (MODIFIED)	SHORTER STUDS AND THREAD LENGTHS	CW 4187	7	-	50	25
PROPELLER GOVERNOR	AND29010 TYPE XX-A (MODIFIED)	R.P.M., STUD LENGTH AND NEGATIVE-TORQUE-SYSTEM SUPPLY PORT	CW 3754	125	188	825	125
PROPELLER PITCH CONTROL	MOUNTING PAD PROVIDED		NONE				30

BASIC ENGINE INCLUDES

- GEARBOX, COMPRESSOR, AND TURBINE SECTIONS; AND TURBINE EXHAUST DIFFUSER.
- FUEL PUMPS, FILTER, FUEL-CONTROL UNIT, FUEL SHUTOFF VALVE, AND FUEL ANTI-ICE HEATING SYSTEM EXCLUDING OIL-TO-FUEL HEAT EXCHANGER (FUEL HEATER).
- DUAL IGNITION SYSTEM, EXCLUDING POWER SOURCE AND ACCESSORY ELECTRICAL WIRING.
- PROPELLER FLANGE (SEE INSTALLATIONS DRAWING) AND ACCESSORY DRIVES.
- INTERSTAGE TURBINE TEMPERATURE-SENSING SYSTEM.
- LUBRICATION SYSTEM, EXCLUSIVE OF OPTIONAL OIL TANK AND RELATED OIL LINES.
- TORQUE SENSOR.
- ENGINE INLET ANTI-ICING SYSTEM, VALVE, AND PLUMBING LINES.

OPTIONAL ACCESSORIES

- PROPELLER-GOVERNOR CONTROL
- PROPELLER-PITCH CONTROL
- OIL TANK AND RELATED PLUMBING
- OIL-TO-FUEL HEAT EXCHANGER (FUEL HEATER) FOR THE FUEL FILTER ANTI-ICING (WITH RELATED PLUMBING)
- PROPELLER OIL-FLOW TUBE
- CONTROLS LINKAGE ASSEMBLY
- TORQUE-SENSOR TRANSMITTER KIT
- TORQUE-SENSOR TRANSMITTER ADAPTER
- OIL TEMPERATURE-SENSING BULB
- NEGATIVE-TORQUE-SENSOR PRESSURE SWITCH
- BETA-PRESSURE-SENSING SWITCH
- OIL PRESSURE SWITCH
- FIRE-SHIELD ADAPTER

3.0 TEST FACILITY AND EQUIPMENT

3.1 Large Altitude Cold Chamber Test Facility

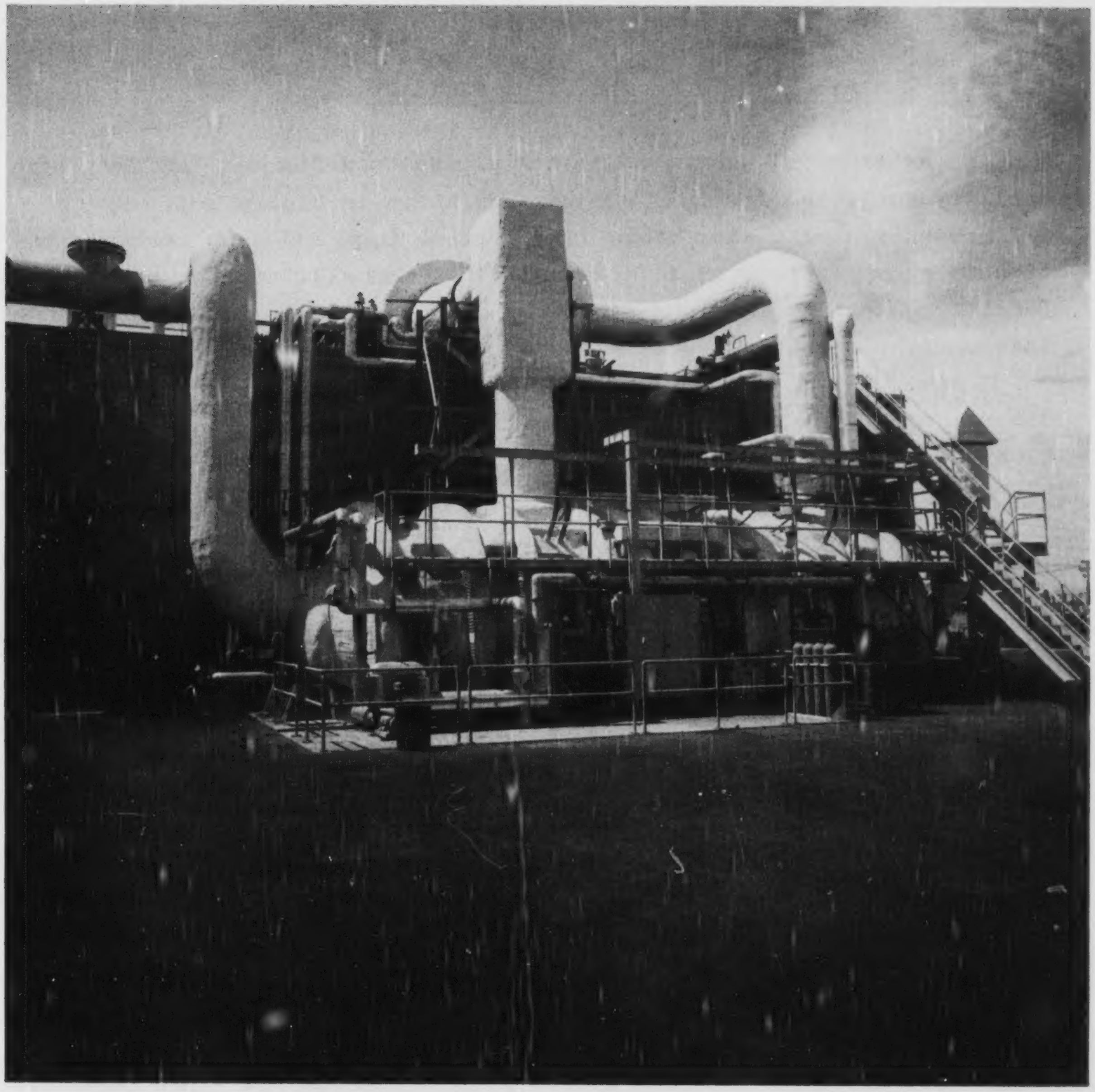
An exterior view of the Large Altitude Cold Chamber (LACC-2) test facility, utilized for this program, is shown in Figure 3-1. Figure 3-2 presents an interior view. The control room and test instrumentation is shown in Figures 3-3 through 3-6. The altitude chamber test facility general dimensions, performance capabilities, special features, instrumentation, and electrical power capabilities are:

Dimensions:

- Overall Length - 11.58 m (38 ft)
- Overall Diameter - 4.57 m (15 ft)
- Inner Chamber Diameter - 4.42 m (14 ft 6 inches)

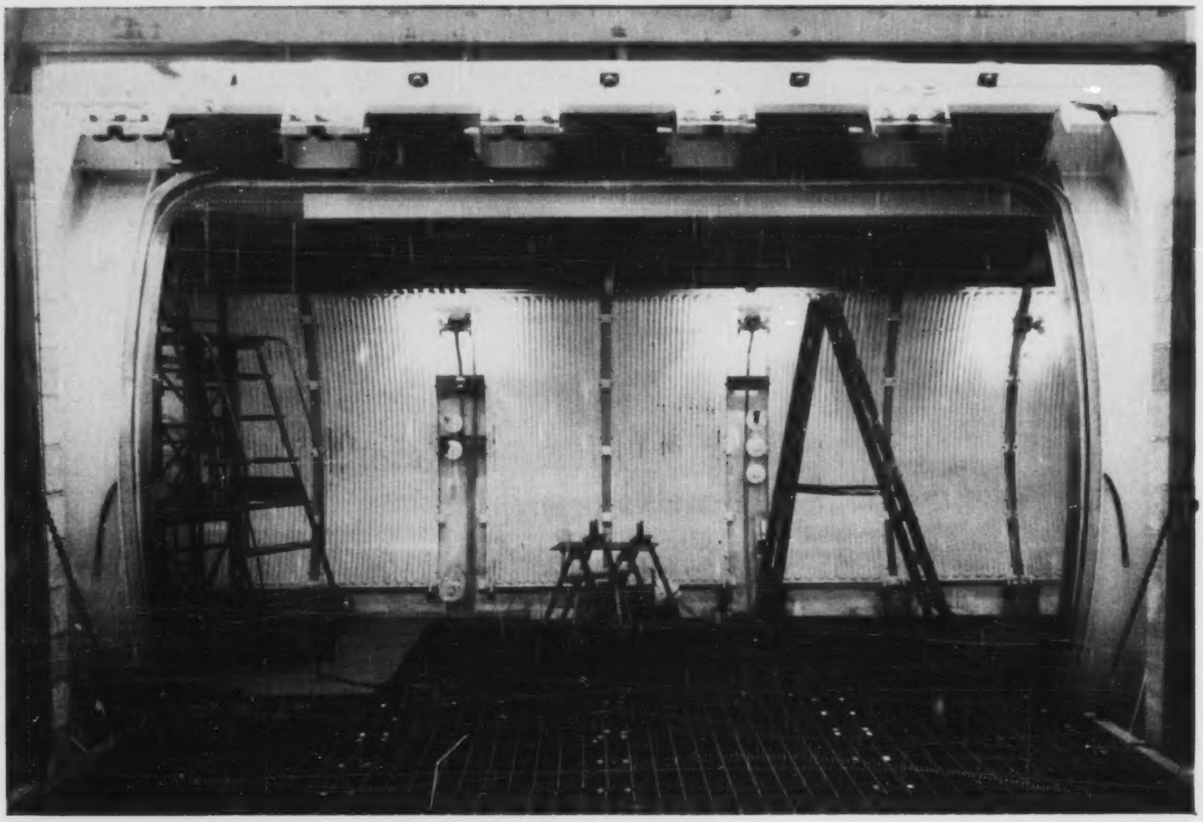
Performance Capabilities:

- Ambient Temperature Range - -56.5°C to 77°C (-65°F to 170°F)(regulated)
- Ambient Pressure Range - 760 mm HgA to 20.71 mm HgA (sea level to 80,000 ft)
- Airflow - Sea Level - 1260 ppm
70,000 ft - 225 ppm
- Compressed Air Supply - -65°F to 990°F (-56.5°C to 532°C) @ 300 psi (2068 kPa)
- Fuel Flow - 0 to 5000 lb/hr (0 to 2268 kg/hr)



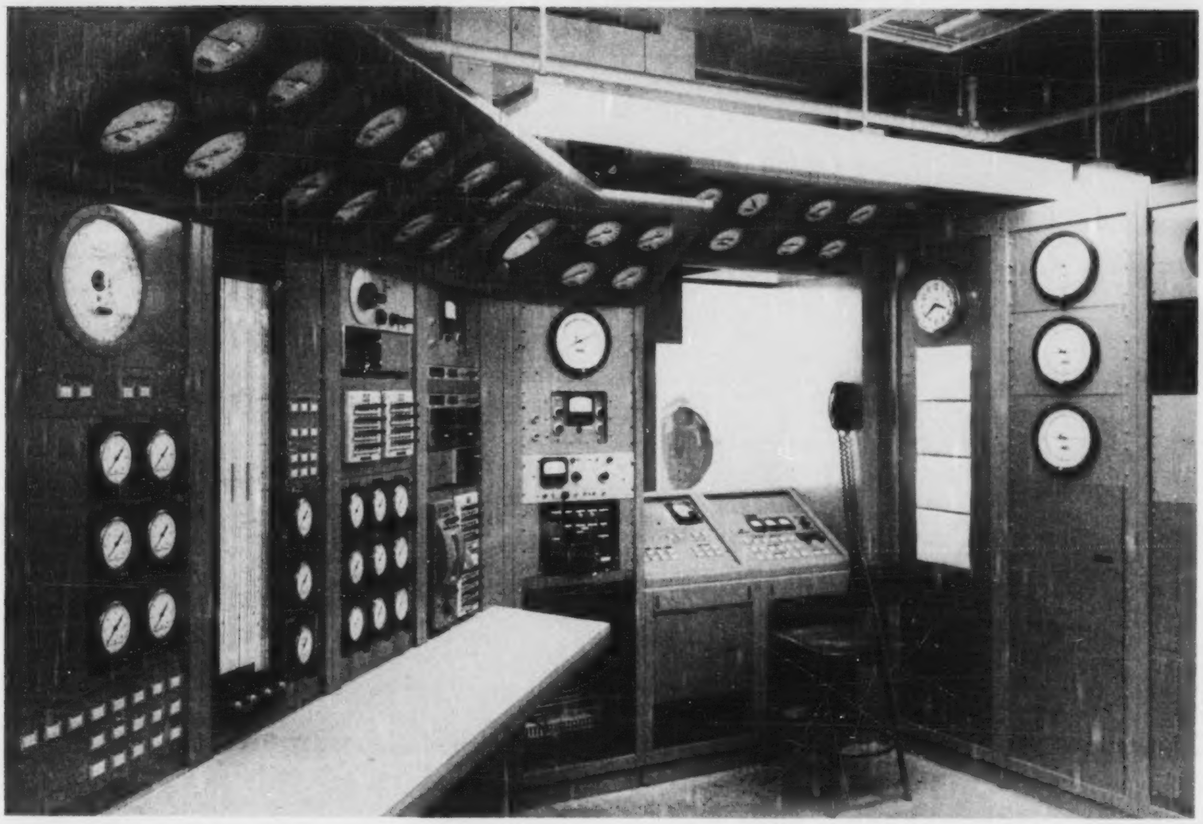
AIRESEARCH-PHOENIX LARGE ALTITUDE
COLD CHAMBER (LACC-2)
(EXTERNAL VIEW)

FIGURE 3-1



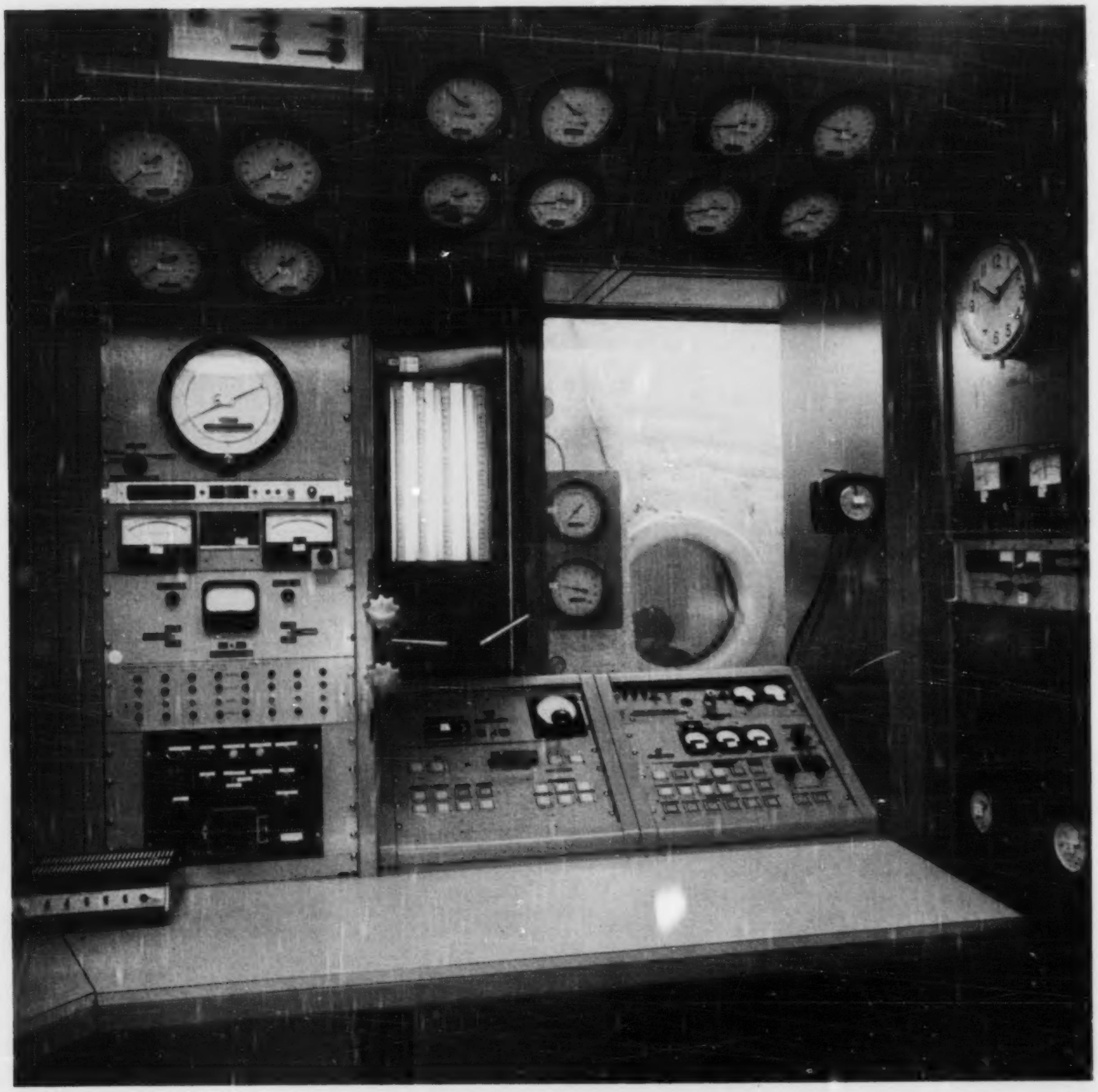
AIRESEARCH-PHOENIX LARGE ALTITUDE COLD CHAMBER (LACC-2)
(INTERIOR VIEW)

FIGURE 3-2



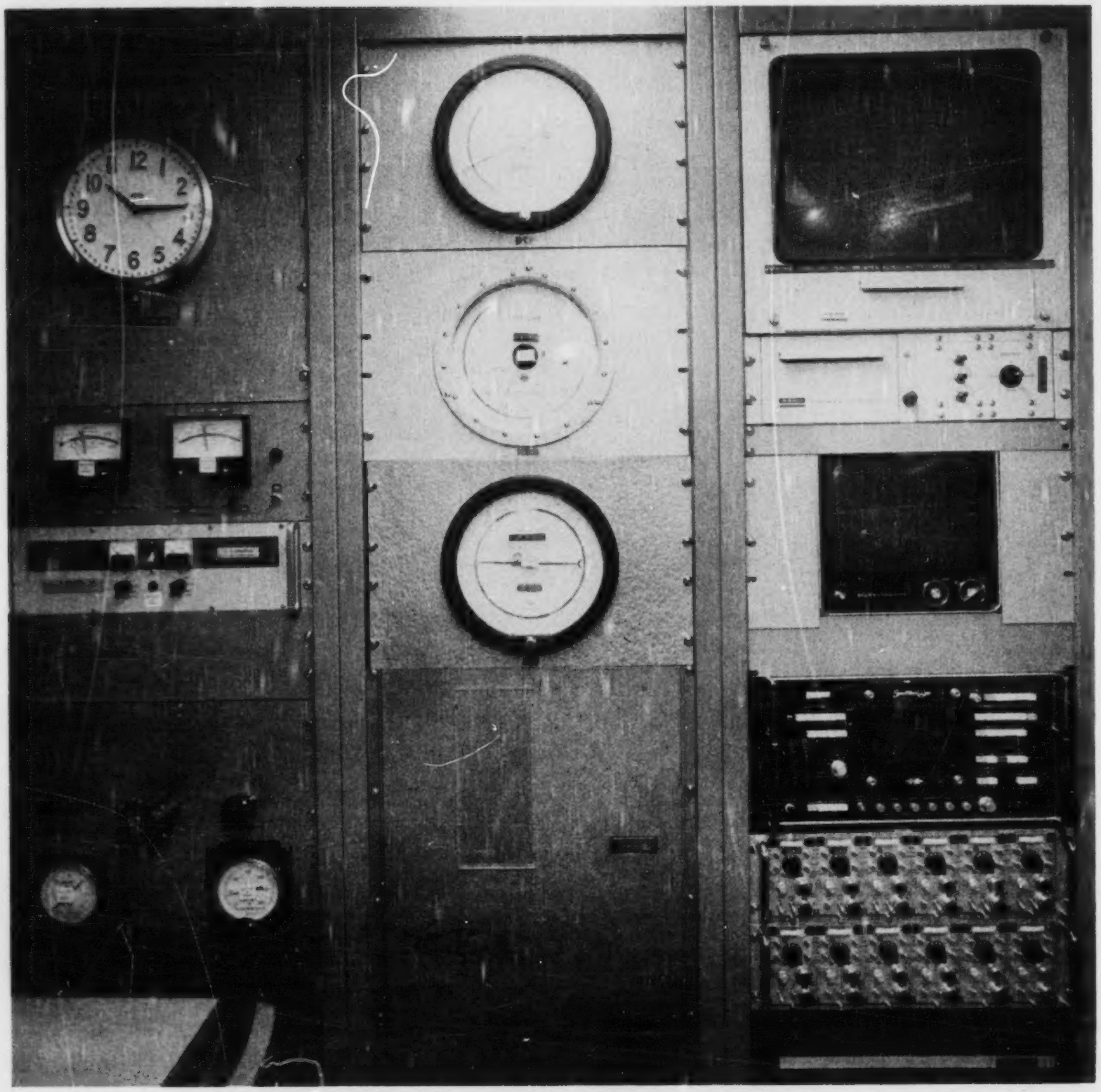
LARGE ALTITUDE COLD CHAMBER CONTROL ROOM

FIGURE 3-3



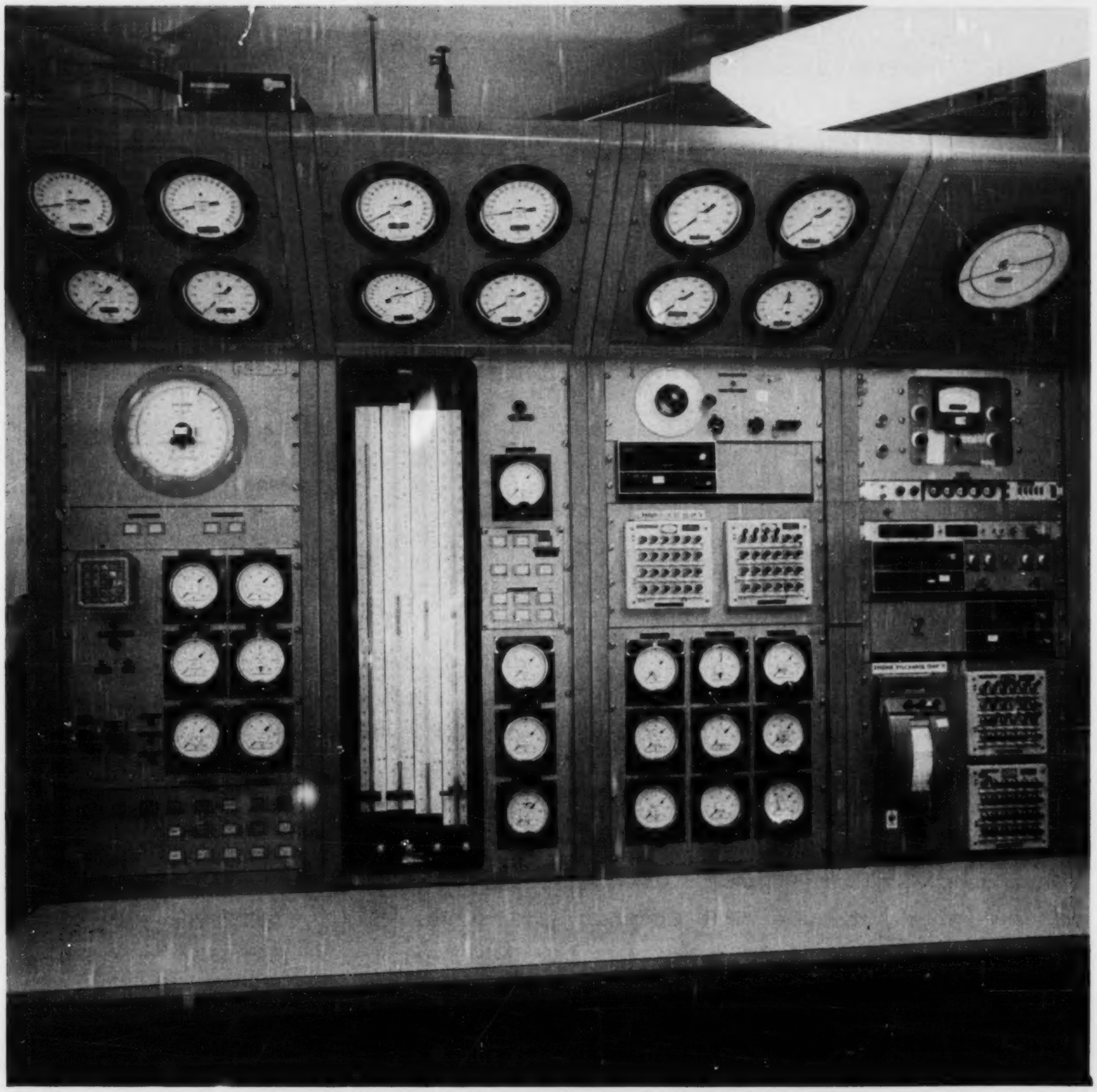
LARGE ALTITUDE COLD CHAMBER
CONTROL CONSOLE

FIGURE 3-4



LARGE ALTITUDE COLD CHAMBER
INSTRUMENTATION CONSOLE (EAST WALL)

FIGURE 3-5



LARGE ALTITUDE COLD CHAMBER
INSTRUMENTATION CONSOLE (WEST WALL)

FIGURE 3-6

Special Features:

- Thrust Measurement to 4000 lb (1814 kg)
- Fuel supplied at matching ambient temperature and pressure

Instrumentation:

- Digital, analog, or visual remote control video camera and tape recording

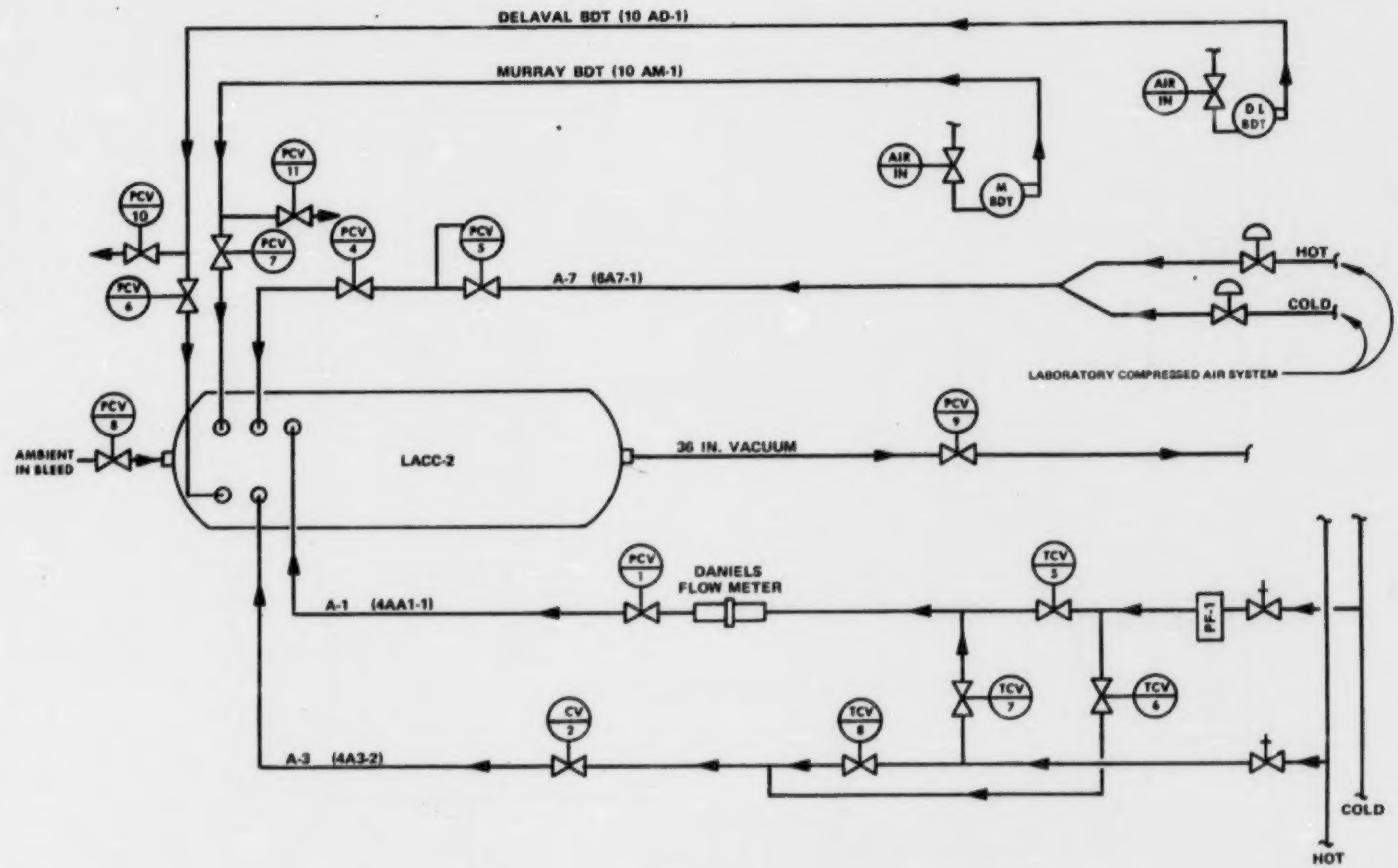
Electrical Power:

- 24 vdc and 110, 220, and 400 vac
- Single wall chamber with cyrogenic panels
- Steam and water injection capability

Air is supplied to the altitude chamber facility from the gas turbine laboratory compressed air system. For continuous operation, this system is comprised of four Clark Model C-RA-4 air compressors rated to deliver air on demand over a pressure range of 120 to 300 psig. The air is routed through the system refrigerated air equipment, or the air heater equipment, to provide the cold and hot air needed for trimming air mixture to a desired temperature. General schematics of the Large Altitude Test Chamber air-vacuum, fuel, and water supply systems, are shown in Figures 3-7 through 3-9.

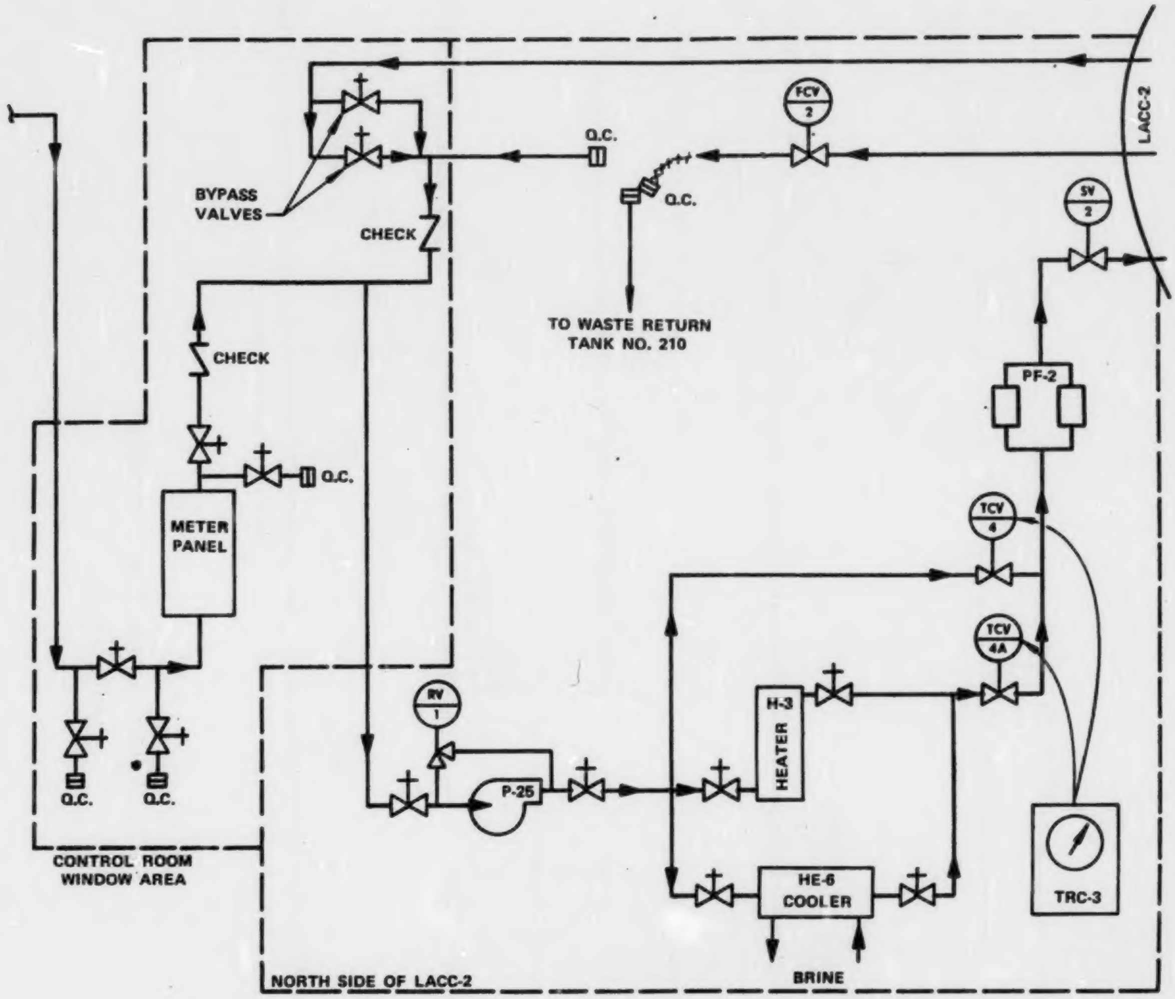
3.1.1 Test Chamber Pressure Limitation

Two areas required special consideration to ensure that the program was successfully conducted. These considerations relate to tank test pressure limitations and difficulty in achieving inlet humidity control.


DELAVAL BDT (10 AD-1)
MURRAY BDT (10 AM-1)
AIR IN
D L BDT
AIR IN
M BDT
PCV 11
PCV 10
PCV 7
PCV 4
PCV 5
PCV 6
A-7 (6A7-1)
HOT
COLD
LABORATORY COMPRESSED AIR SYSTEM
PCV 8
AMBIENT IN BLEED
LACC-2
36 IN. VACUUM
PCV 9
PCV 1
DANIELS FLOW METER
TCV 5
PF-1
A-1 (4AA1-1)
TCV 7
TCV 6
CV 2
TCV 8
A-3 (4A3-2)
COLD
HOT

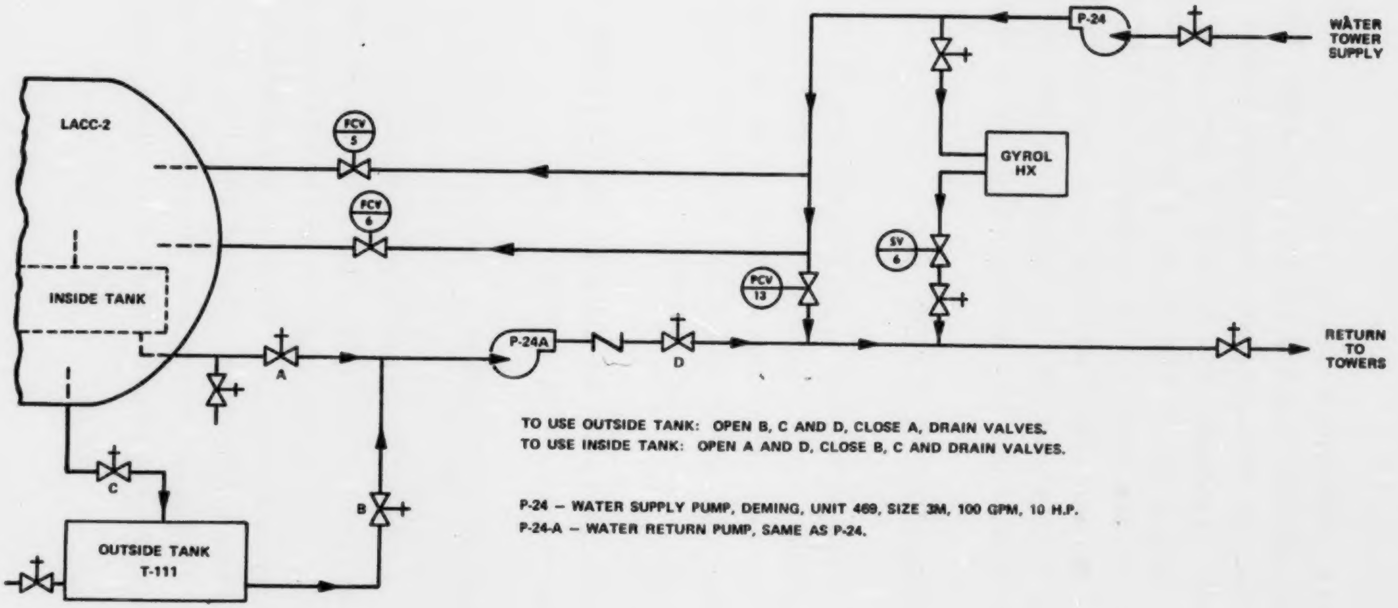
LACC-2 AIR & VACUUM SYSTEMS

FIGURE 3-7


BYPASS VALVES
CHECK
Q.C.
FCV 2
Q.C.
LACC-2
TO WASTE RETURN TANK NO. 210
SV 2
CHECK
PF-2
Q.C.
METER PANEL
TCV 4
TCV 4A
RV 1
H-3
HEATER
P-25
Q.C.
Q.C.
HE-6 COOLER
TRC-3
CONTROL ROOM WINDOW AREA
NORTH SIDE OF LACC-2
BRINE

LACC-2 FUEL SYSTEM

FIGURE 3-8


WATER TOWER SUPPLY
P-24
GYROL HX
SV 6
FCV 5
FCV 6
FCV 13
LACC-2
INSIDE TANK
A
B
C
D
P-24A
OUTSIDE TANK T-111
RETURN TO TOWERS

TO USE OUTSIDE TANK: OPEN B, C AND D, CLOSE A, DRAIN VALVES.
TO USE INSIDE TANK: OPEN A AND D, CLOSE B, C AND DRAIN VALVES.

P-24 – WATER SUPPLY PUMP, DEMING, UNIT 469, SIZE 3M, 100 GPM, 10 H.P.
P-24-A – WATER RETURN PUMP, SAME AS P-24.

LACC-2 TOWER WATER SUPPLY
& RETURN SYSTEM

FIGURE 3-9

Altitude pressure reductions can be simulated with the described test chamber, but the chamber cannot be pressurized. Therefore, the original pressure level of Ambient Test Condition Number 16, 820 mm Hg could not be attained. Instead, the effect of pressure up to and including a barometric pressure of 740 mm Hg (approximately the prevailing ambient pressure at the laboratory elevation of 342 meters (1122 feet) was measured. To provide a variation in barometric pressure for statistical purposes that would be equivalent to the desired range, AiResearch conducted Condition 16, at 500 mm Hg instead of 820 mm Hg.

3.1.2 Humidity Control Considerations

Accurate water content control, at the engine inlet, was considered imperative to ensure that proper ambient test conditions were being maintained. It was determined at test program initiation that only direct measurement of water and airflows could assure that proper humidity conditions were being maintained.

Difficulties encountered with attempting to create true humidity; i.e., amount of water vapor in air, were:

- Engine airflow of 8 lb/sec
- The broad range of ambient test conditions (i.e., test conditions 1 and 2 at -7°C, shown in Table 1-2) present substantial difficulty in preventing icing conditions from occurring. The high temperature, high humidity test conditions (10 through 12) required great care that cooler surfaces did not come in contact with the humidified air which results in water condensation.

- Independent control of engine inlet temperature and pressure
- The requirement for no ram pressure and temperature rise at the engine inlet

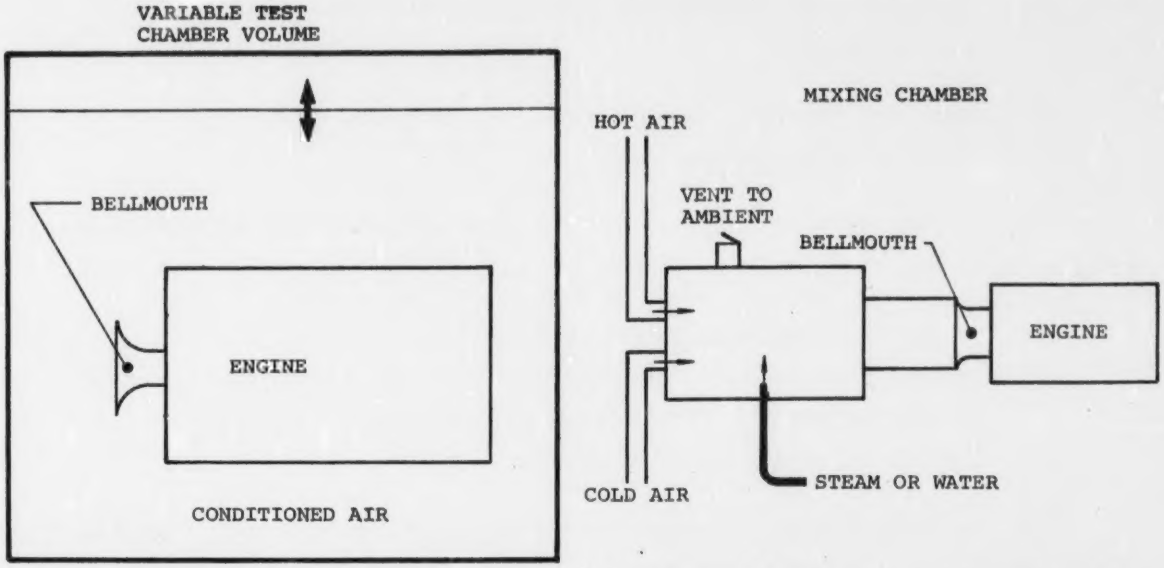
Four types of humidity control systems listed below and shown in Figure 3-10 were considered prior to selecting the candidate system:

- Total environment control
- Steam injection or water injection in the mixing plenum
- Water injection into the hot air line
- Water injection at the engine inlet

The initial method considered was a total environment system that would humidify a chamber of air with sufficient size to operate the engine at a discrete test point. This system was rejected due to the; high airflows involved, range of inlet air conditions that required simulation, and unacceptable size and expense of incorporating such a system.

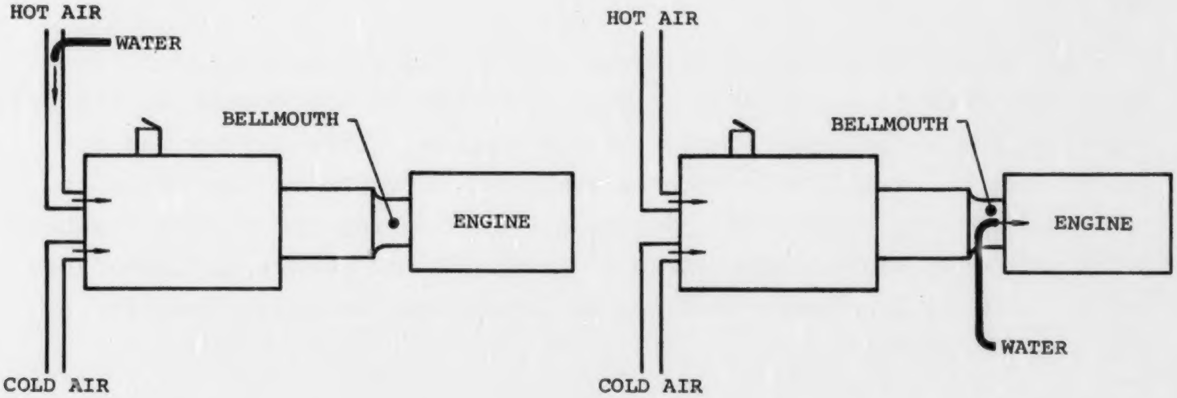
An alternate system considered was to inject steam and/or fine water droplets in the mixing chamber upstream of the engine to mix and vaporize the water before entering the engine. This system was rejected due to excessive distances required to vaporize the water at the temperatures available. Secondly, the ducting and mixing chambers metal surfaces would cause steam to condense and adhere to these surfaces, forming droplets resulting in lower than expected humidity at the engine inlet.

The third system considered was to add the water required for a given humidity in the hot line of the mixing process. This system was rejected since the cold air stream would cool surfaces in the mixing chamber to the point where condensation would occur.


VARIABLE TEST
CHAMBER VOLUME
BELLMOUTH
ENGINE
CONDITIONED AIR
MIXING CHAMBER
HOT AIR
VENT TO
AMBIENT
BELLMOUTH
ENGINE
COLD AIR
STEAM OR WATER

TOTAL ENVIRONMENT CONTROL

WATER/STEAM INJECTION INTO MIXING CHAMBER


HOT AIR
WATER
BELLMOUTH
ENGINE
COLD AIR
HOT AIR
BELLMOUTH
ENGINE
WATER
COLD AIR

WATER INJECTION INTO HOT AIR LINE

WATER INJECTION AT ENGINE INLET

HUMIDITY CONTROL SYSTEMS SCHEMATICS

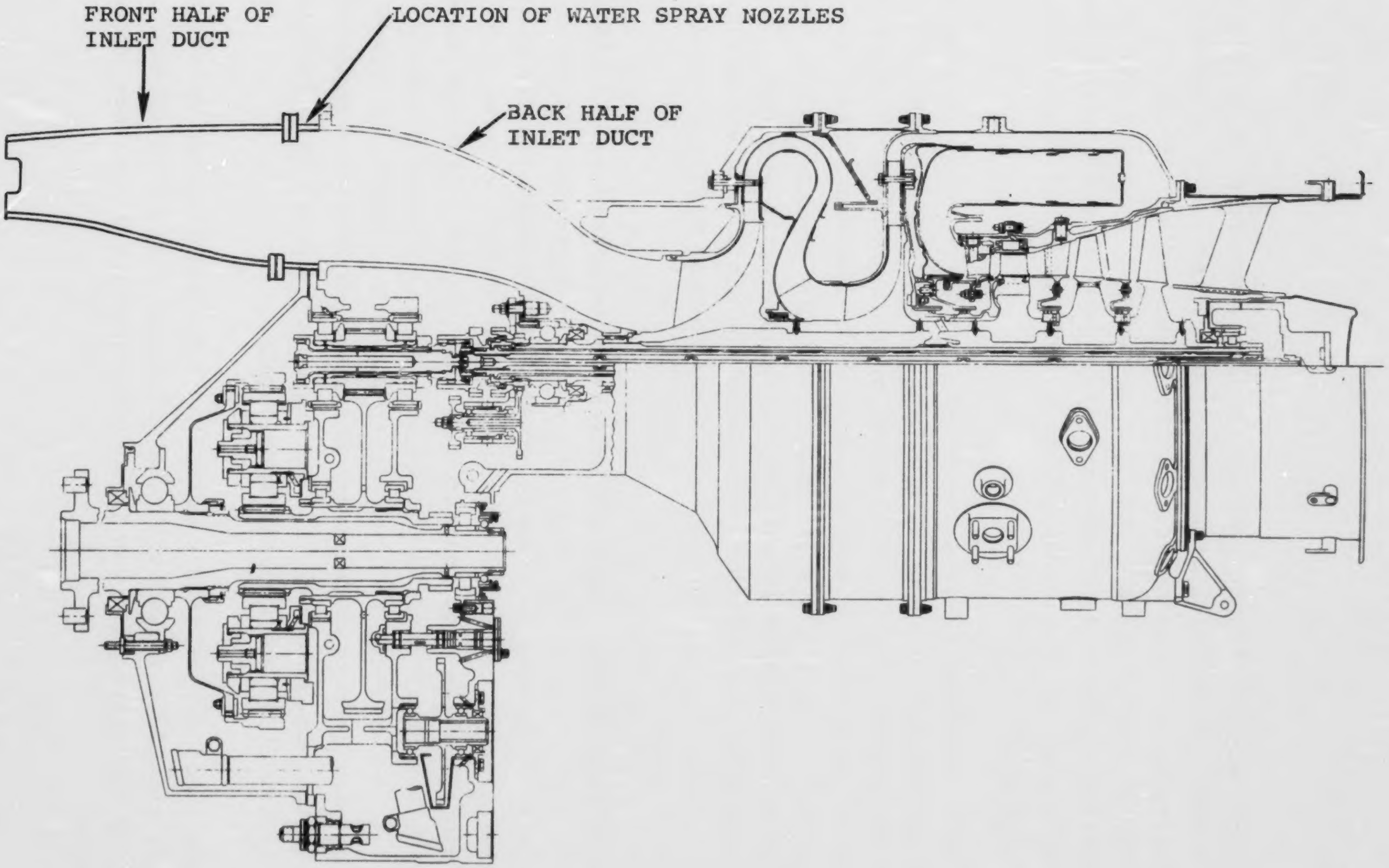
FIGURE 3-10

A second, more difficult problem is also involved in this and the previous humidity simulation technique. The engine inlet condition must be maintained with no ram air at the engine inlet. Since ram-air is controlled by a value in the mixing chamber, moisture can be lost by venting into the altitude tank, thus producing lower than expected humidity at the engine inlet due to the amount of water injection into the hot air line.

The final humidity simulation system considered, and eventually selected, was the injection of fine water droplets immediately upstream of the engine inlet. This system avoided problems of icing and condensation that the other methods would encounter and assured an accurate measurement of water introduced into the engine. Also, the system expense was commensurate with available program funding. It must be clearly recognized that this method is not a true simulation of humidity since the liquid water must absorb heat from the engine to reach a vapor state.

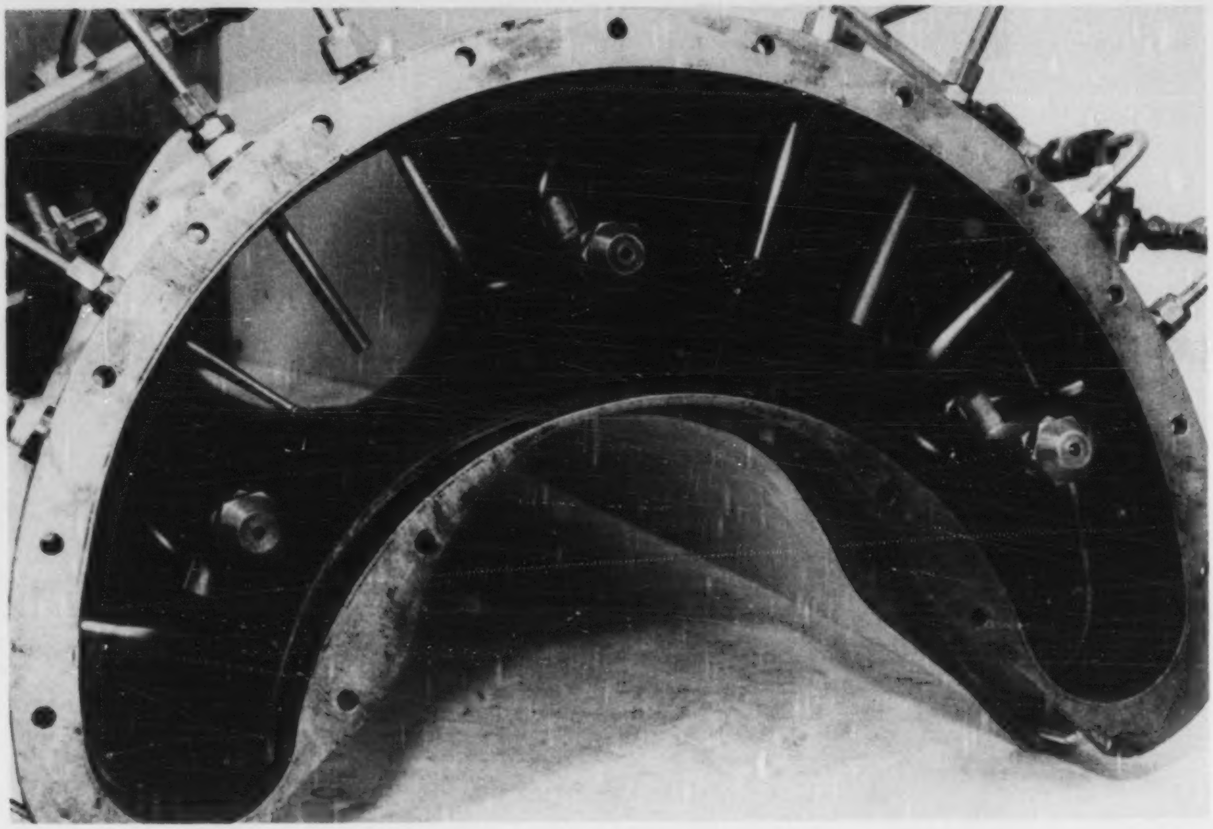
This process lowers compressor discharge temperature. In addition, total flow through the engine is slightly increased and the air specific heat is changed to a small extent. Unfortunately, these are unavoidable by-products of this technique, and should be taken into account when utilizing data presented in this report. Although some vaporization may occur outside the engine compressor, which lowers the engine inlet temperature, this effect is negligible since the temperature measurement instrumentation and nozzles were located immediately upstream of the engine inlet. This arrangement is shown in Figures 3-11, 3-12, 3-13, and 3-14, for the turboprop engine.

In the remainder of this report, the word humidity and reference to humidity should be viewed with the knowledge that humidity was simulated by fine water droplet injection immediately upstream of the engine inlet.


FRONT HALF OF
INLET DUCT
LOCATION OF WATER SPRAY NOZZLES
BACK HALF OF
INLET DUCT

CROSS SECTION OF TPE331-3U-303 SHOWING LOCATION OF WATER SPRAY NOZZLES

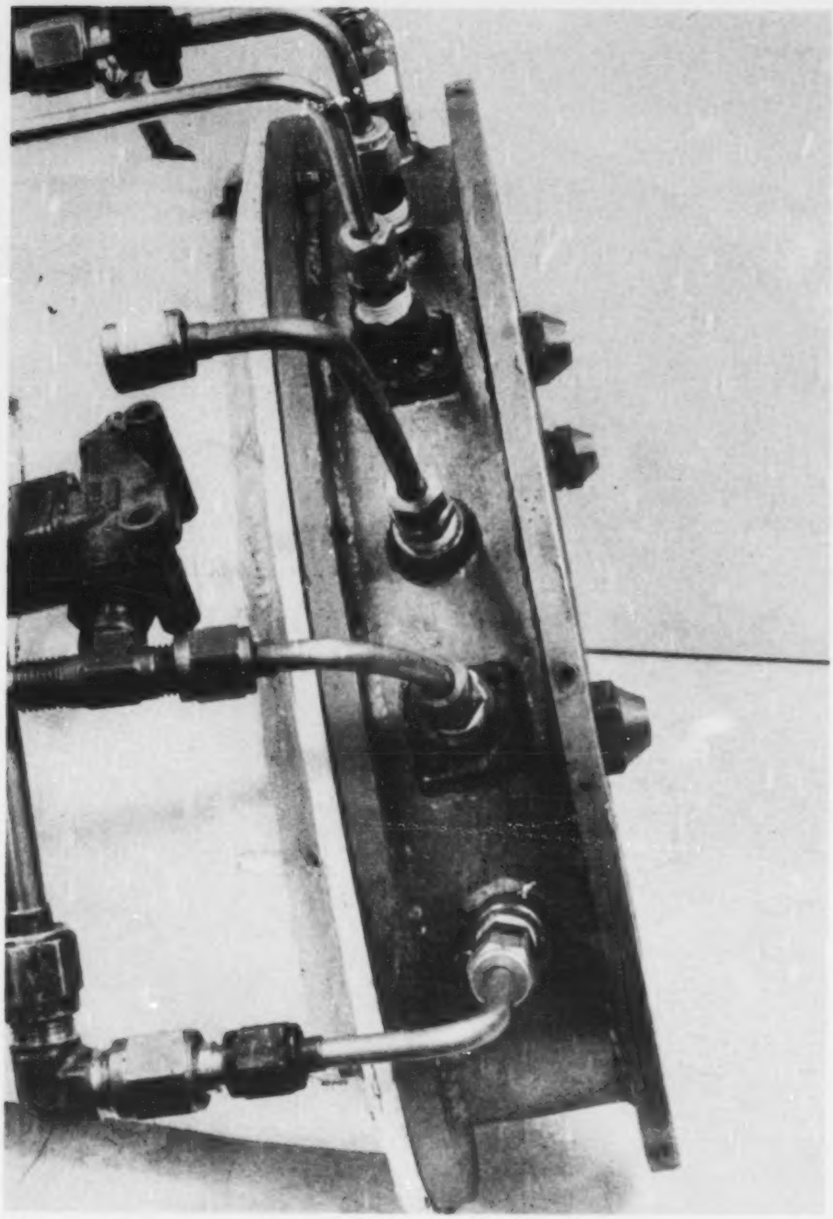
FIGURE 3-11



WATER SPRAY NOZZLES LOCATED ON FRONT HALF TPE331 ENGINE INLET DUCTING (AFT LOOKING FORWARD)

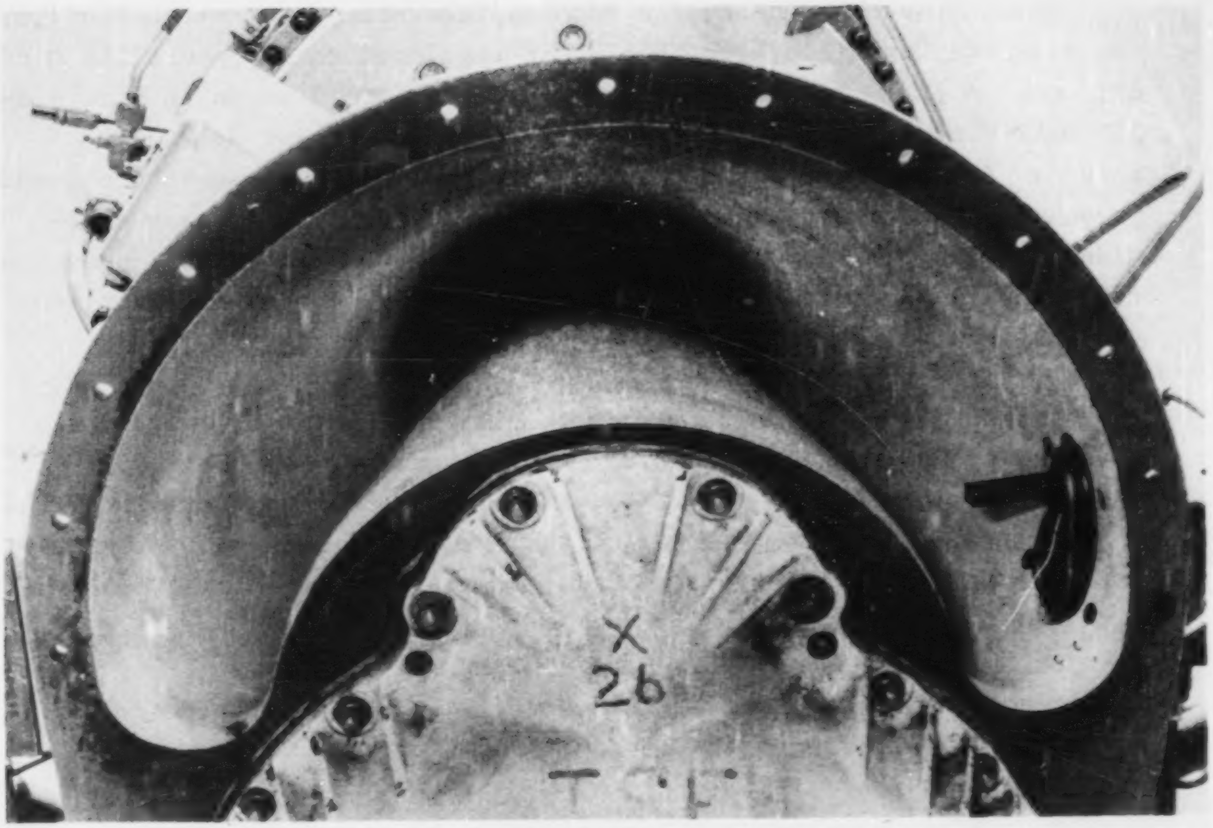
FIGURE 3-12

MP-50946



SIDE VIEW OF SPACER DUCT CONTAINING WATER SPRAY NOZZLES

FIGURE 3-13



BACK HALF OF TPE331 ENGINE INLET
(FORWARD LOOKING AFT)

FIGURE 3-14

3.2 Combustion Rig Test Facility

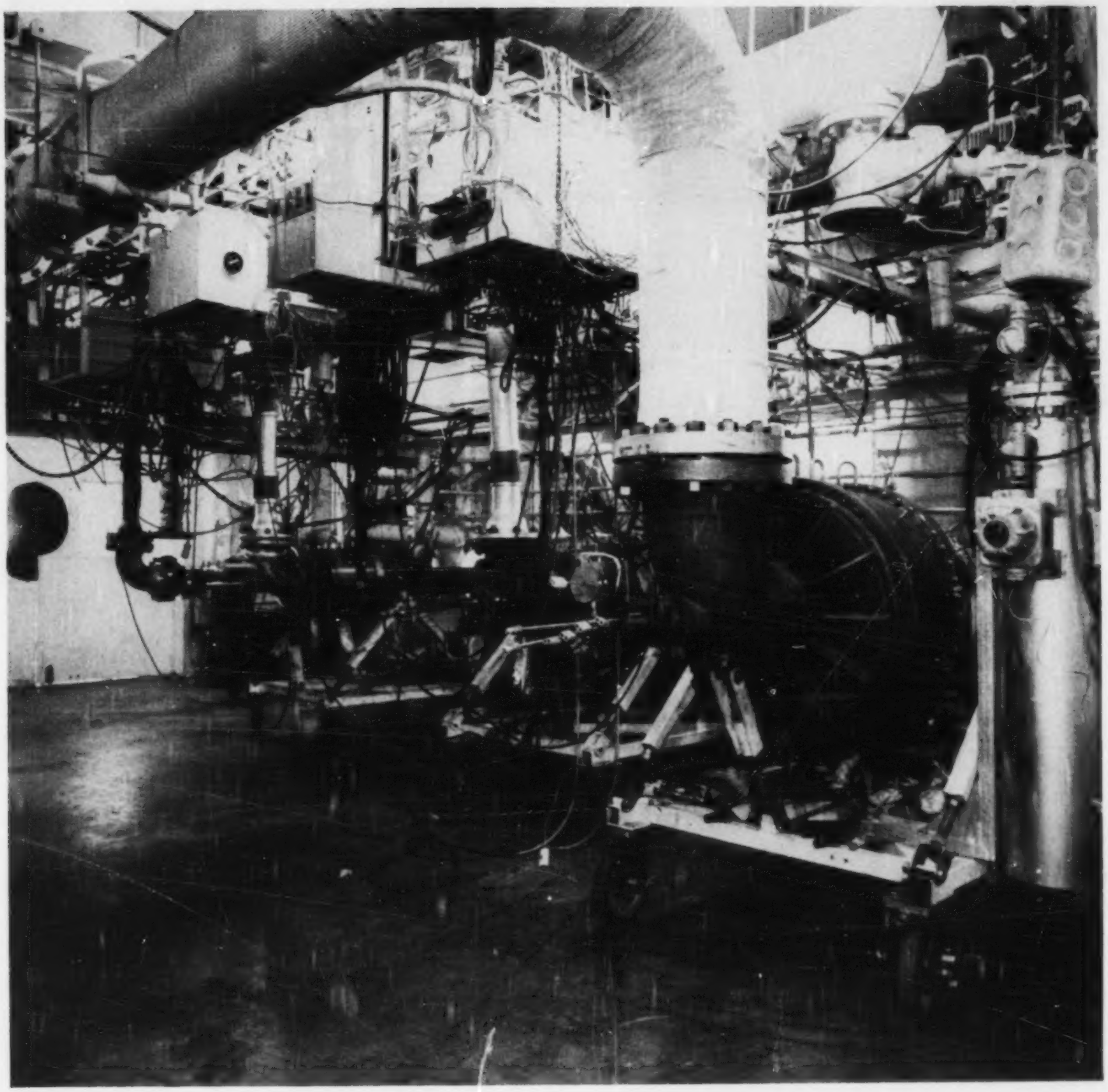
The AiResearch-Phoenix gas turbine laboratory combustion facility provides the capability for testing at simulated engine operating conditions. A photograph of the test cell interior is shown in Figure 3-15, with control panel photographs in Figures 3-16 and 3-17. The facility is instrumented to measure air, fuel flows, temperatures, and pressures, necessary to determine performance factors such as efficiency, discharge temperature pattern factor, combustor total pressure drop, ignition characteristics, flame stability, combustor liner temperature and emissions.

Pressure levels from minus 30 to plus 300 inches of mercury are measured by using highly accurate pressure gauges. A total of 14 channels are available; and if additional pressure measurements are required, a scanner valve with 48 channels can be utilized. Temperature levels measured and types of thermocouples used are as follows:

- Iron-constantan (100° to 1000°F), 24 channels
- Chromel-alumel (0° to 2400°F), 94 channels
- Platinum-rhodium (0° to 3000°F), 24 channels

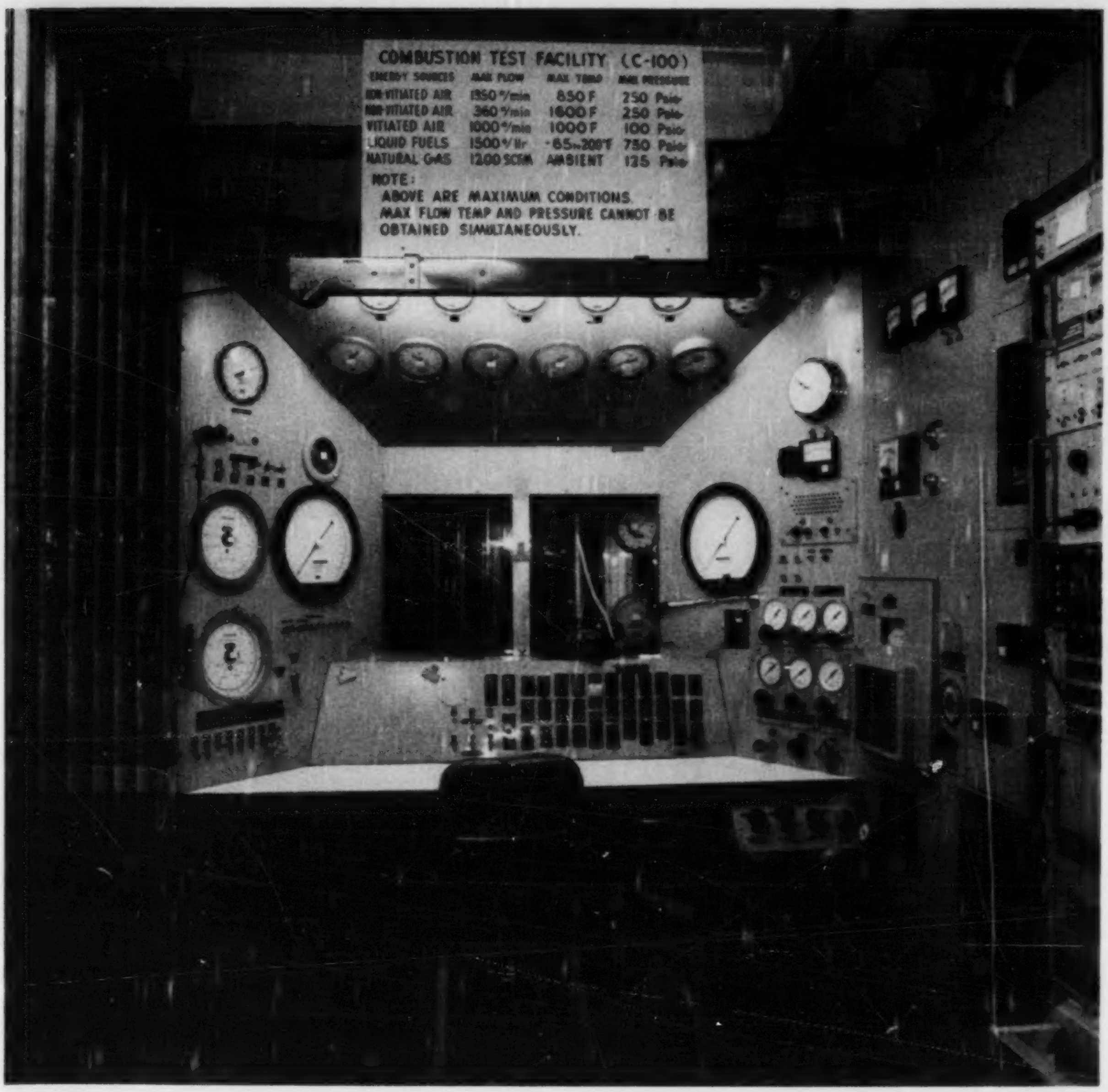
Liquid fuel flow is measured by means of five rotometers with a range of 4 to 1000 pounds per hour. A weight rate fuel flow measurement system is also available. Airflows are measured in accordance with standard ASME orifice metering practice. Data is recorded manually, and by means of a digital recorder.

Nonvitiated air is supplied to the main laboratory combustion facility by a bank of compressors and heaters. Air temperature can be regulated from ambient to 850°F. At 800°F, airflow and pressure capabilities are approximately 9 pounds per second and 100 psi,



COMBUSTION TEST FACILITY (C-100)

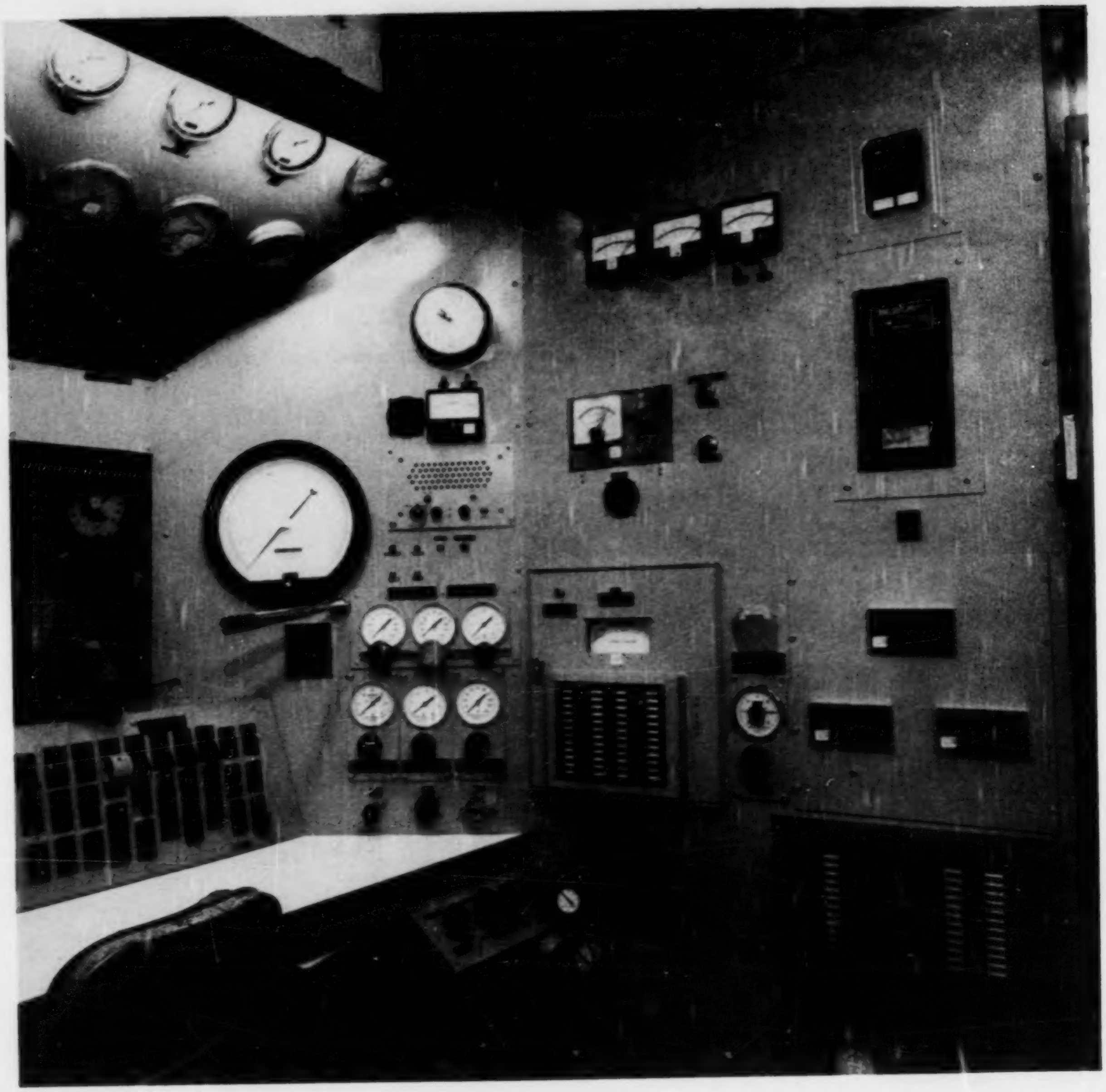
FIGURE 3-15


COMBUSTION TEST FACILITY (C-100)
ENERGY SOURCES MAX FLOW MAX TEMP MAX PRESSURE
NON-VITIATED AIR 1350 #/min 850 F 250 Psig
NON-VITIATED AIR 360 #/min 1600 F 250 Psig
VITIATED AIR 1000 #/min 1000 F 100 Psig
LIQUID FUELS 1500 #/Hr -65 to 200°F 750 Psig
NATURAL GAS 1200 SCFM AMBIENT 125 Psig
NOTE:
ABOVE ARE MAXIMUM CONDITIONS.
MAX FLOW TEMP AND PRESSURE CANNOT BE
OBTAINED SIMULTANEOUSLY.

CONTROL PANEL

FIGURE 3-16

Reproduced from best available copy.



CONTROL PANEL (EAST WALL)

FIGURE 3-17

respectively. Higher airflows and pressures are possible at lower temperatures. A special preheater provides nonvitiated air at 1200°F at flows to 6 pounds per second and at pressures to 250 psi.

Expansion turbines can be used with the laboratory vacuum system to provide low temperature air (to -30°F) to the test rigs for altitude ignition studies. The combustion facility has the capability of providing liquid fuels to the test rigs at flows to 1500 pounds per hour and pressures to 750 psi. Fuel temperature can be regulated from -65°F to 200°F. Natural gas can also be supplied to the test rigs at flows to 1200 cubic feet per minute and at pressures to 200 psi.

3.3 Gaseous Emission Analyzing Equipment

All gaseous emission testing, conducted during this program, conformed to specifications defined by title 40 Code of Federal Regulations (40 CFR 87). In accordance with these specifications all gaseous emission samples were taken "wet". That is, no desiccants, dryers, water traps, or related equipment was used to treat exhaust samples flowing to emissions measurement instrumentation.

Continuous monitoring of pollutant levels was performed during the test phase with equipment described in this section. Manufacturer's data, including principles of operation and model specifications, are presented in Appendix I. Emissions-analyzing equipment was installed in a truck (Figure 3-18) equipped with an environmental control system. The instrumentation shown installed, in the truck, can be described as follows:

(a) A Beckman Model 402 hot flame-ionization-detection hydrocarbon analyzer capable of discriminating unburned hydrocarbons in the sample over a range of 0.1 parts per million to 50,000 ppm.

(b) A Thermo Electron Model 10A chemiluminescent NO_x analyzer for determining the presence of oxides of nitrogen over a range from 0 to 10,000 ppm.

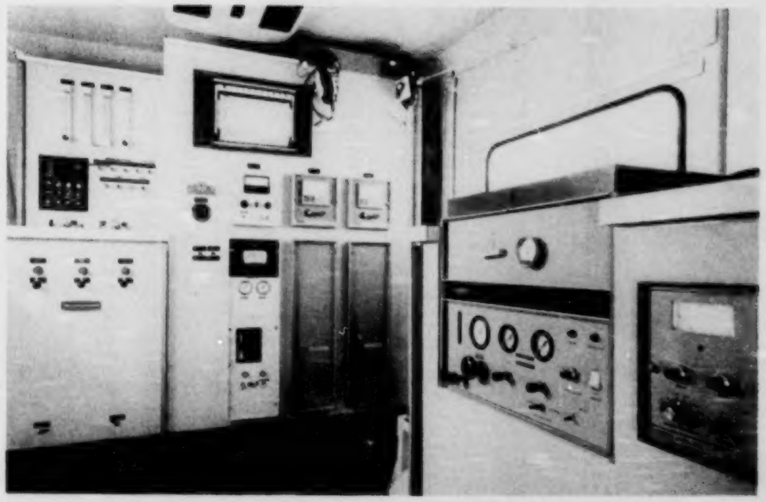
(c) A Beckman Model 315B carbon monoxide analyzer. This analyzer has three discrete sensitivity ranges, corresponding to 0 to 100 ppm, 0 to 500 ppm, and 0 to 2500 ppm.

(d) A Beckman Model 315B used to analyze carbon dioxide. The sensitivity ranges of this analyzer correspond

AIRESEARCH

EMISSION ANALYZER
MOBILE UNIT

GAS MEASURED	INSTRUMENT
OXIDES OF NITROGEN	CHEMILUMINESCENT ANALYZER
HYDROCARBONS	FLAME IONIZATION DETECTOR
CARBON MONOXIDE CARBON DIOXIDE	NON-DISPERSIVE INFRARED ANALYZER



MOBILE EMISSIONS ANALYZER TRUCK

FIGURE 3-18

to; 0 to 2 percent, 0 to 5 percent, and 0 to 15 percent. (The measurement of carbon dioxide is not specifically required for determining pollutant emission rates. However, AiResearch conducts analyses of carbon dioxide in engine exhaust gases to provide a carbon balance with the fuel consumed as a means of checking the test data validity.)

All instruments, zero gases, and span gases are kept at a constant temperature to avoid drift. The equipment is capable of continuously monitoring CO, CO_2, NO, NO_x, and unburned hydrocarbons in exhaust gases. Test results are recorded automatically when required. Table 3-1 shows the zero and span gases used to calibrate the instruments.

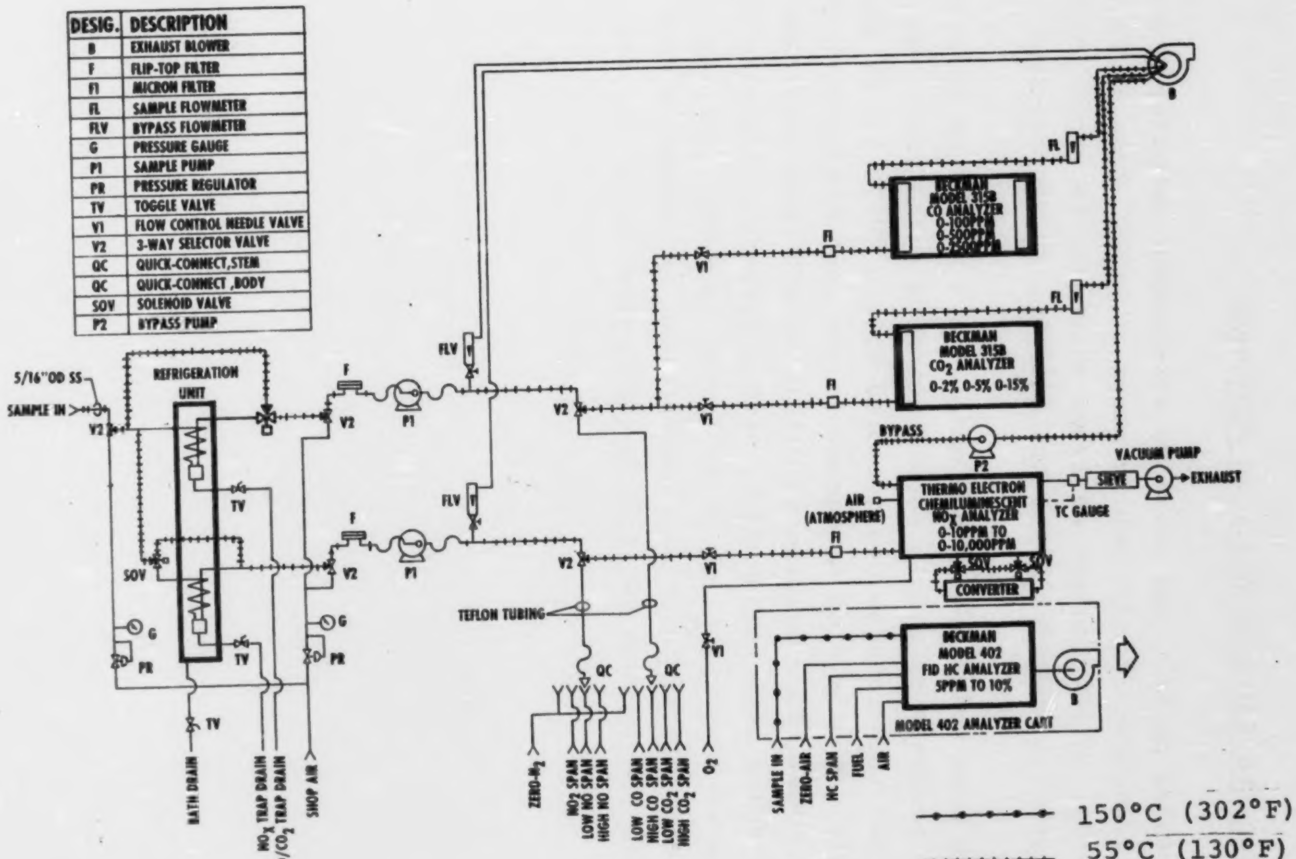
TABLE 3-1

ZERO AND SPAN GASES

Gas	Concentration	Manufacturer
Zero air and N_2	HC < 1 ppm	Air Products
C_3H_8 (Propane) in air	6.3 ppm 52.0 ppm 105.0 ppm	Air Products
NO in N_2	16.9 ppm 46.5 ppm 109.0 ppm	Scott Research Labs
CO_2 in N_2	1.05% 1.97% 3.05%	Scott Research Labs
CO in N_2	65 ppm 250 ppm 440 ppm	Air Products

A complete gaseous emissions analysis system flow diagram is shown in Figure 3-19.

All temperature measurements required by Federal specifications were monitored on digital readout equipment. All temperatures, pertinent "dial in" instrumentation changes, gain, and scale ranges were hand recorded on appropriate data sheets, a sample of which is included in Appendix II.



DESIG.	DESCRIPTION
B	EXHAUST BLOWER
F	FLIP-TOP FILTER
FI	MICRON FILTER
FL	SAMPLE FLOWMETER
FLV	BYPASS FLOWMETER
G	PRESSURE GAUGE
P1	SAMPLE PUMP
PR	PRESSURE REGULATOR
TV	TOGGLE VALVE
V1	FLOW CONTROL NEEDLE VALVE
V2	3-WAY SELECTOR VALVE
QC	QUICK-CONNECT,STEM
QC	QUICK-CONNECT ,BODY
SOV	SOLENOID VALVE
P2	BYPASS PUMP

5/16"OD SS
SAMPLE IN
V2
REFRIGERATION UNIT
SOV
G
PR
TV
BATH DRAIN
NO_X TRAP DRAIN
CO/CO_2 TRAP DRAIN
SHOP AIR
F
V2
P1
FLV
B
FL
BECKMAN MODEL 315B CO ANALYZER 0-100PPM 0-500PPM 0-2500PPM
BECKMAN MODEL 315B CO_2 ANALYZER 0-2% 0-5% 0-15%
FI
V1
BYPASS
P2
VACUUM PUMP
SIEVE
EXHAUST
TC GAUGE
AIR (ATMOSPHERE)
THERMO ELECTRON CHEMILUMINESCENT NO_X ANALYZER 0-10PPM TO 0-10,000PPM
SOV
CONVERTER
TEFLON TUBING
QC
ZERO-N_2
NO_2 SPAN
LOW NO SPAN
HIGH NO SPAN
LOW CO SPAN
HIGH CO SPAN
LOW CO_2 SPAN
HIGH CO_2 SPAN
O_2
BECKMAN MODEL 402 FID HC ANALYZER 5PPM TO 10%
MODEL 402 ANALYZER CART
SAMPLE IN
ZERO-AIR
HC SPAN
FUEL
AIR
150°C (302°F)
55°C (130°F)

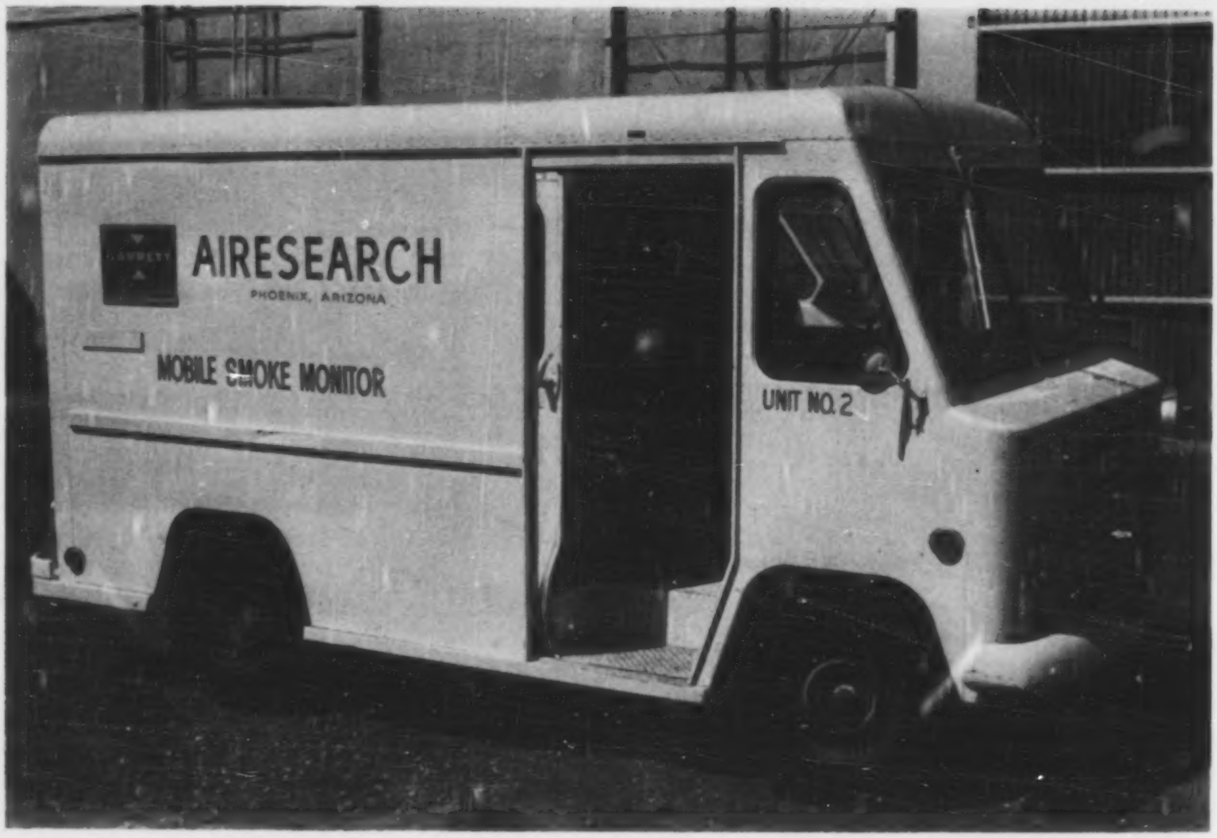
GAS ANALYZER FLOW SYSTEM

FIGURE 3-19

3.4 Particulate Emission Analysis Equipment

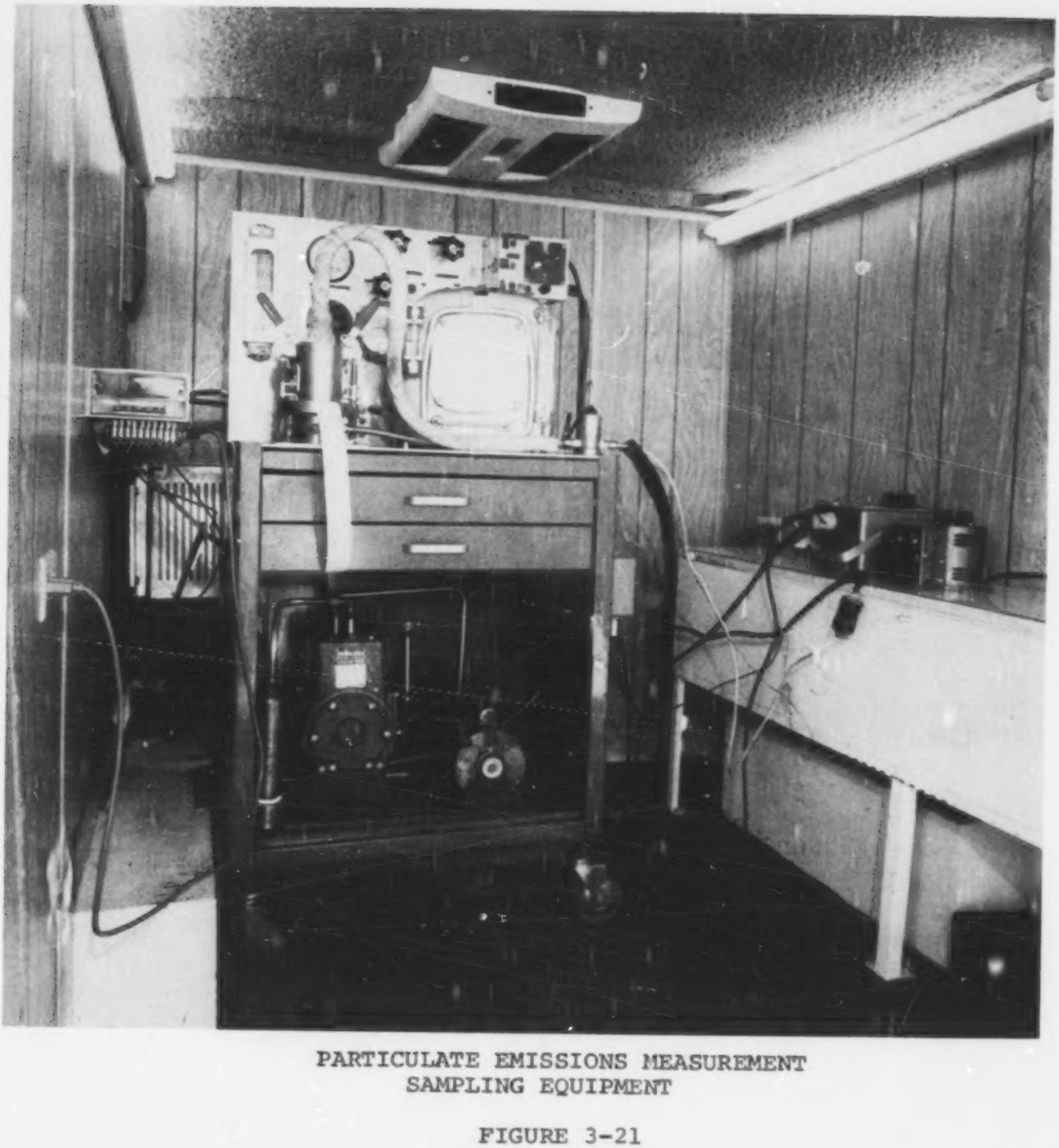
All engine particulate emission measurement sampling was conducted with the AiResearch-Phoenix mobile smoke analyzer shown in Figures 3-20 and 3-21. A particulate analyzer schematic is shown in Figure 3-22, and a general description of the analyzer is as follows:

Sample size measurements are made with a Precision Scientific Wet Test Meter accurate to within ±0.005 standard cubic foot. Wet test pressures and temperatures are measured within ±0.02 in. Hg and ±1°F, respectively. Sample flow measurements are conducted with a Brooks Rotometer, Model 110, accurate to within ±0.017 cubic foot per minute. A Duo-Seal Model 1405 vacuum pump, with a free-flow capacity of 2 cfm and no-flow vacuum capability of 1 micron, is used. All sampling lines and associated plumbing are maintained above the emission sample ambient dew point to prevent water from condensing out of the gas.


GARRETT
AIRESEARCH
PHOENIX, ARIZONA
MOBILE SMOKE MONITOR
UNIT NO. 2

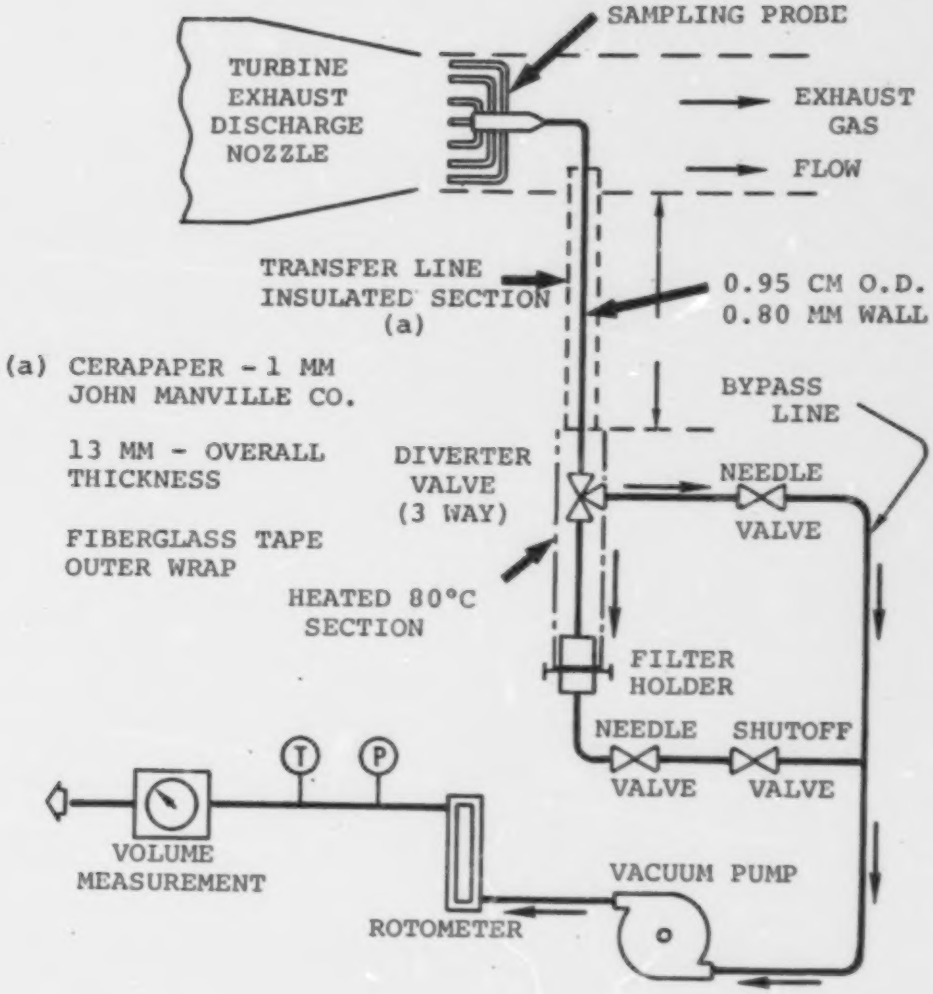
PARTICULATE EMISSION ANALYSIS TRUCK

FIGURE 3-20



PARTICULATE EMISSIONS MEASUREMENT
SAMPLING EQUIPMENT

FIGURE 3-21


SAMPLING PROBE
TURBINE EXHAUST DISCHARGE NOZZLE
EXHAUST GAS FLOW
TRANSFER LINE INSULATED SECTION (a)
0.95 CM O.D.
0.80 MM WALL
(a) CERAPAPER - 1 MM JOHN MANVILLE CO.
13 MM - OVERALL THICKNESS
FIBERGLASS TAPE OUTER WRAP
BYPASS LINE
DIVERTER VALVE (3 WAY)
NEEDLE VALVE
HEATED 80°C SECTION
FILTER HOLDER
NEEDLE VALVE
SHUTOFF VALVE
T
P
VOLUME MEASUREMENT
VACUUM PUMP
ROTOMETER

PARTICULATE SAMPLING SYSTEM
FOR GAS TURBINE ENGINES

FIGURE 3-22

4.0 DESCRIPTION OF TEST

4.1 GTCP85-98CK APU Engine Testing

AiResearch Engine Model GTCP85-98CK (APU) S/N 36179 testing, was conducted in the AiResearch-Phoenix Large Altitude Cold Chamber (LACC-2) during June 4 through June 20, 1975. The testing consisted of recording gaseous and particulate emission levels at the five engine load conditions listed in Table 4-1 at each of the sixteen engine inlet ambient conditions listed in Table 4-2. At each ambient condition, it was required that the five engine load conditions be repeated for a total of three readings. This was accomplished by repeating Condition 1 through Condition 5 (in sequence) three times. For each of the 16 listed ambient conditions, the following test procedure was accomplished:

(a) The engine was started and accelerated to no-load governed speed.

(b) The specific ambient conditions tested (Table 4-2) were established in the test chamber and the engine was allowed to reach steady-state conditions (approximately 5 minutes).

(c) The first engine load (Condition 1, shown in Table 4-1) was applied to the engine, after stabilization, and all required manual and automatically measured data was recorded. Gaseous and particulate emissions samples were taken consecutively.

(d) The engine load condition was then set to Condition 2 of Table 4-1, allowed to stabilize, and the recording procedure of Condition 1 was repeated.

TABLE 4-1

APU ENGINE LOAD CONDITIONS
(Corrected to 59°F and 29.92 in. Hg abs)

Condition	Load	Horsepower		
		Shaft	Bleed-Air	Total
1	Idle	-	-	-
2	Shaft Only	79.5	0	79.5
3	Rated	198.6	0	198.6
4	Bleed-Air Only	-	245.0	245.0
5	Shaft and Bleed Air	45.7	214.3	260.0

TABLE 4-2

AMBIENT TEST CONDITIONS

Test Operating Condition	Temperature		Humidity		Barometric Pressure	
	°C	°F	Grams H_2O/ Kilogram Air	Grains H_2O/ Pound Air	mm Hg	inches Hg
1	-7.2	19	1.0	7.0	Hold constant at standard condition, as specified in U.S. Standard Atmosphere, 1962, for test cell altitude.	
2	-7.2	19	2.0	14.0		
3	3.9	39	2.0	14.0		
4	3.9	39	5.0	35.0		
5	15.0	59	2.0	14.0	↓	
6	↓	↓	5.0	35.0		
7			7.5	52.5		
8			10.0	70.0		
9	32.8	91	10.0	70.0		
10	↓	↓	15.0	105.0		
11			20.0	140.0		
12			25.0	175.0		
13	15.0	59	7.5	52.5	580	22.83
14	↓	↓	↓	↓	660	25.98
15					740	29.13
16					500	19.69

(e) The above procedure was repeated for engine load Conditions 3 through 5, sequentially, with manual and emission data recorded at each condition.

(f) After Condition 5, the engine was recycled back to load Condition 1 and with the same ambient condition remaining as for the last cycle, the engine was varied from Condition 1 to Condition 5, sequentially, for a second time. The procedure was repeated a third time with all required emissions and manual data being recorded at each engine load condition.

(g) At completing the third engine load condition cycle, the ambient condition was set to a new ambient inlet and the three-cycle engine load condition series described above were repeated.

To avoid confusion between data recorded by the smoke analyzer operator, gaseous emissions analyzer operator, and test cell operator, all test conditions were numbered as test points with Test Point 1 being ambient Condition 1, engine load Condition 1, cycle 1, and the last test point, number 240, as ambient Condition 16, engine load Condition 5, cycle 3. The described test point numbering scheme for all conditions evaluated in this test series is presented in Table 4-3.

A sample data recorded by the test cell operator and a strip chart recording from the gaseous emission analyzer are given in Appendix II as typical data recorded at each test point number.

The data gathered during testing was reduced by computer programs available at AiResearch. The reduced computer data for all 240 test points is presented in Volume 2 of this report. To minimize human error caused by misreading raw data, the computer-reduced output data

TABLE 4-3

APU TEST POINT NUMBER MATRIX

Ambient Condition (Table 4-2)	Engine Load Data Points		
	Cycle 1	Cycle 2	Cycle 3
1	1 - Cond 1*	6 - Cond 1	11 - Cond 1
	2 - Cond 2*	7 - Cond 2	12 - Cond 2
	3 - Cond 3*	8 - Cond 3	13 - Cond 3
	4 - Cond 4*	9 - Cond 5	14 - Cond 4
	5 - Cond 5*	10 - Cond 5	15 - Cond 5
2	16 - Cond 1	21 - Cond 1	26 - Cond 1
	17 - Cond 2	22 - Cond 2	27 - Cond 2
	18 - Cond 3	23 - Cond 3	28 - Cond 3
	19 - Cond 4	24 - Cond 4	29 - Cond 4
	20 - Cond 5	25 - Cond 5	30 - Cond 5
3	31 - 35	36 - 40	41 - 45
4	46 - 50	51 - 55	56 - 60
5	61 - 65	66 - 70	71 - 75
6	76 - 80	81 - 85	86 - 90
7	91 - 95	96 - 100	101 - 105
8	106 - 110	111 - 115	116 - 120
9	121 - 125	126 - 130	131 - 135
10	136 - 140	141 - 145	146 - 150
11	151 - 155	156 - 160	161 - 165
12	166 - 170	171 - 175	176 - 180
13	181 - 185	186 - 190	191 - 195
14	196 - 200	201 - 205	206 - 210
15	211 - 215	216 - 220	221 - 225
16	226 - Cond 1	231 - Cond 1	236 - Cond 1
	227 - Cond 2	232 - Cond 2	237 - Cond 2
	228 - Cond 3	233 - Cond 3	238 - Cond 3
	229 - Cond 4	234 - Cond 4	239 - Cond 4
	230 - Cond 5	235 - Cond 5	240 - Cond 5

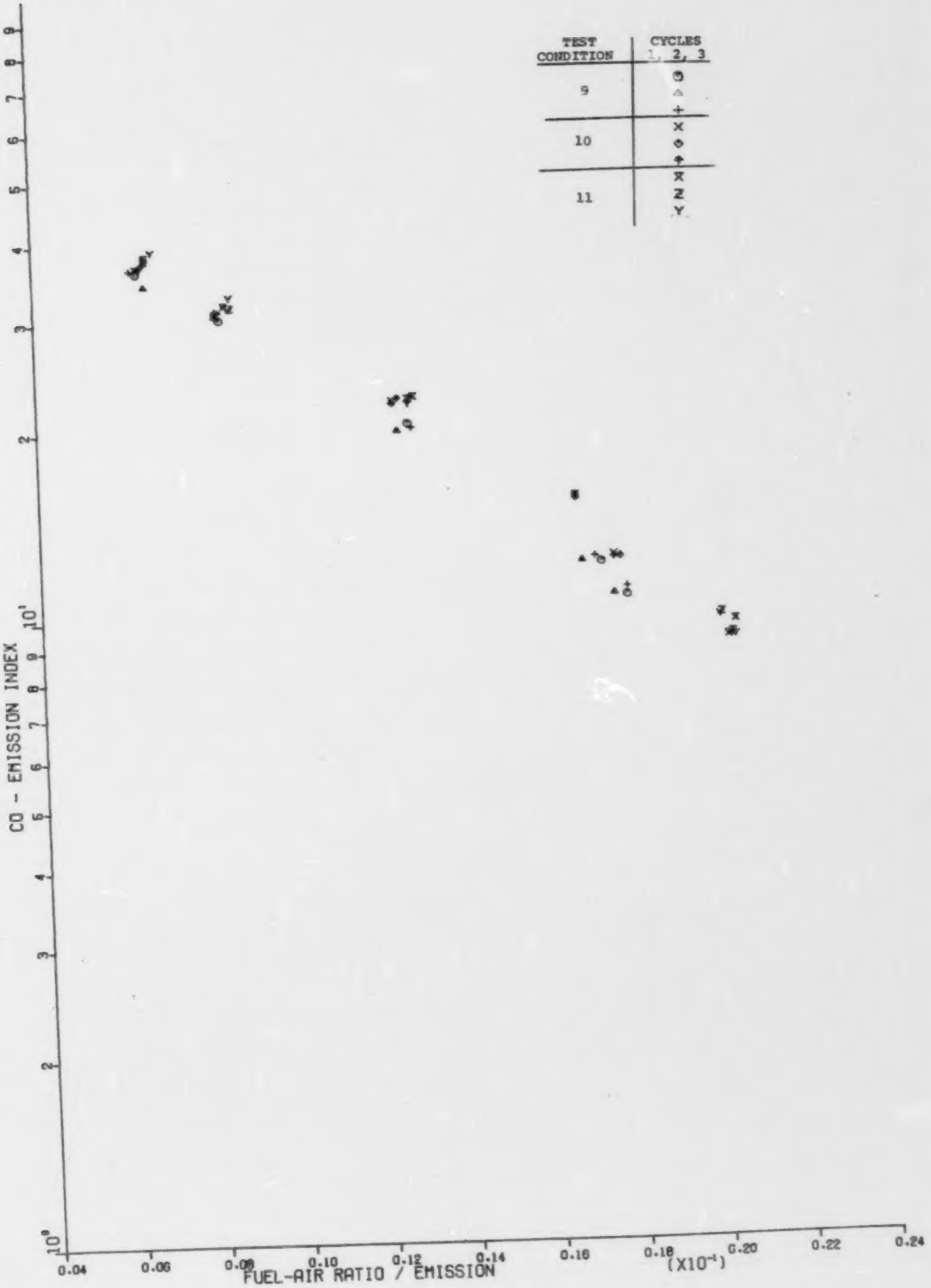
*Conditions 1 through 5 of Table 4-1

was machine plotted by the AiResearch CalComp digital plotter. Example plots are presented in Figures 4-1 through 4-5. All data was machine plotted in this manner to best observe, and correct, data reduction errors.

The GTCP85-98CK Engine completed installation in the test cell is shown by Figures 4-6, 4-7, and 4-8. The engine inlet air temperature is controlled by combining hot and cold air in the pre-mixing chamber shown in Figures 4-6 and 4-7. Water injection nozzles, used to simulate humidity, are located immediately upstream from the engine inlet. The water nozzles are operated individually or in combination depending on water flow requirements. Atomization is air-assisted to aid in producing small uniform water droplets. The nozzles produce a droplet Sauter Mean Diameter (SMD) of 19.0 microns at 100 psig air-assist air pressure and at average water flow rates for the test conditions simulated.

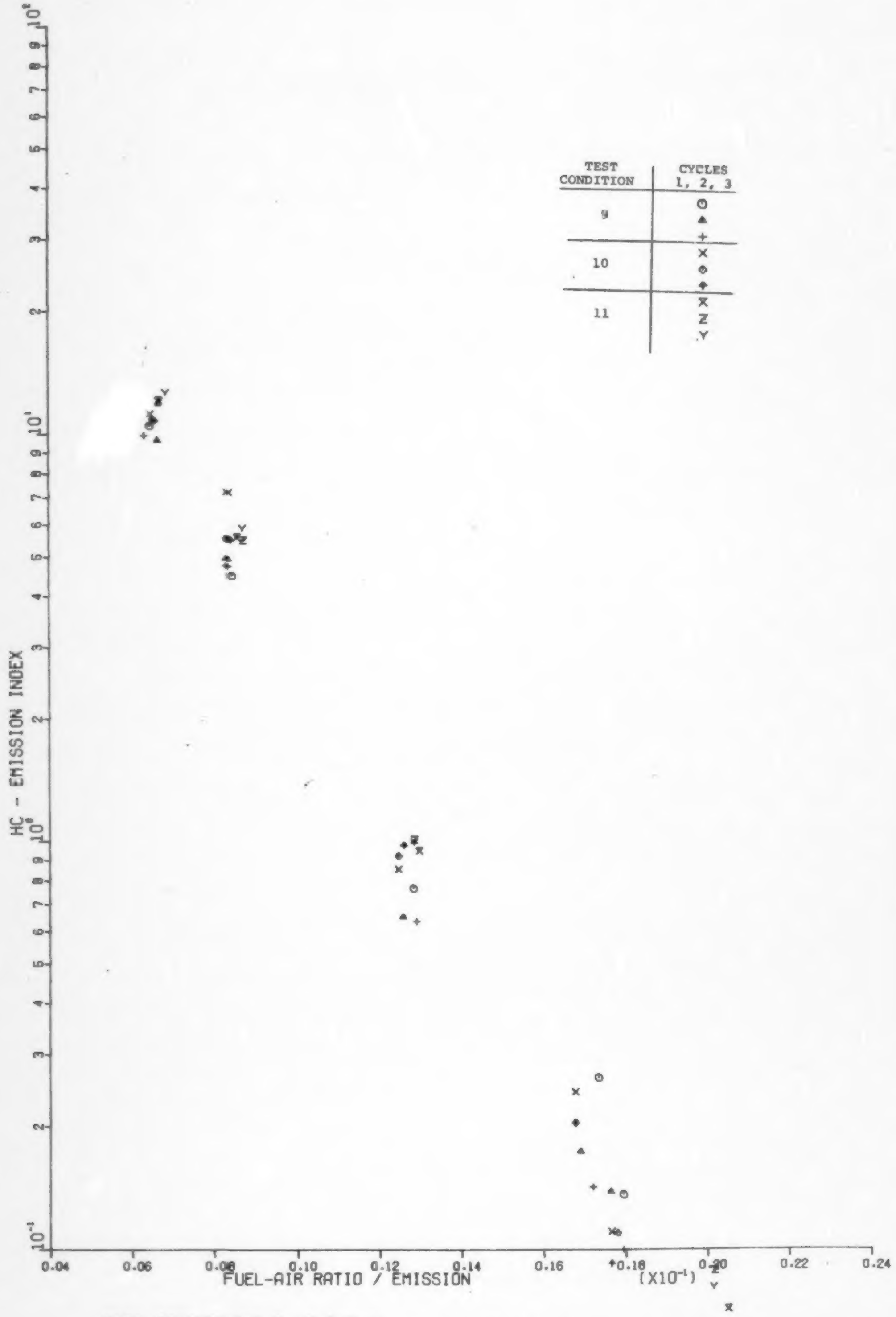
Emissions sampling and measuring equipment are contained in the two mobile vans shown in Figure 4-9. The vans are parked outside the test chamber and instrumentation connecting apparatus are run between the test article (installed in the controlled atmosphere chamber) and vans.

The heated emissions sample line was routed out of the test chamber where a three-way electrically activated solenoid valve directed the flow to the smoke sampling equipment, or the gaseous emission sampling equipment. All sample lines were heated to approximately 300°F (148.9°C) during the test to prevent condensation of heavy hydrocarbons from the gas sample. Downstream of the three-way solenoid valve in the gaseous sample line branch, a vacuum booster pump was installed when simulated altitude test conditions (13, 14, and 16) were conducted. This was necessary because the pump within the Beckman 402 hydrocarbon analyzer was unable to draw a gas sample from the test chamber when simulated altitude test conditions were run. A schematic drawing of the emission sample line system is shown in Figure 4-10.



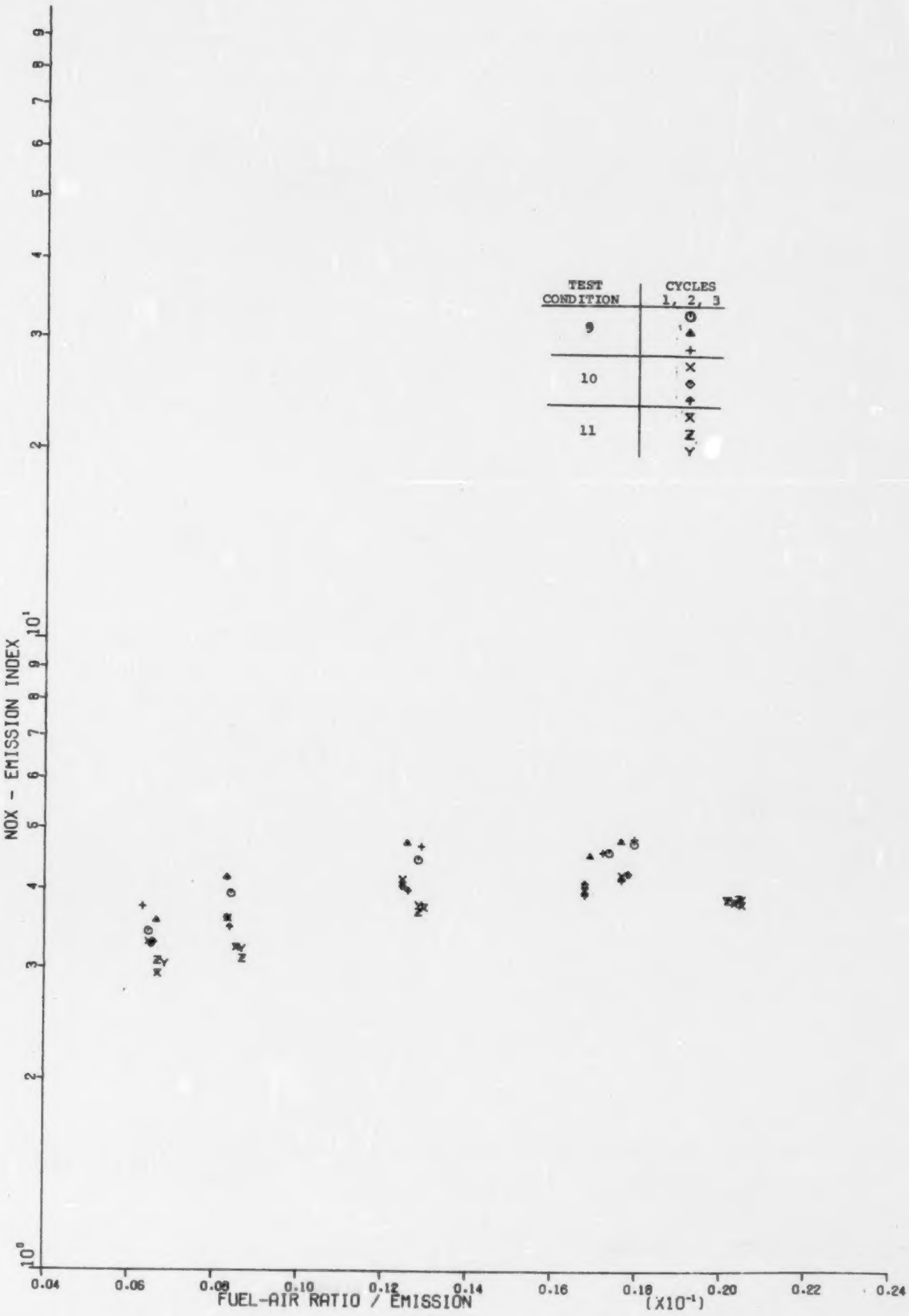
TEST CONDITIONS 9.10.AND 11

FIGURE 4-1



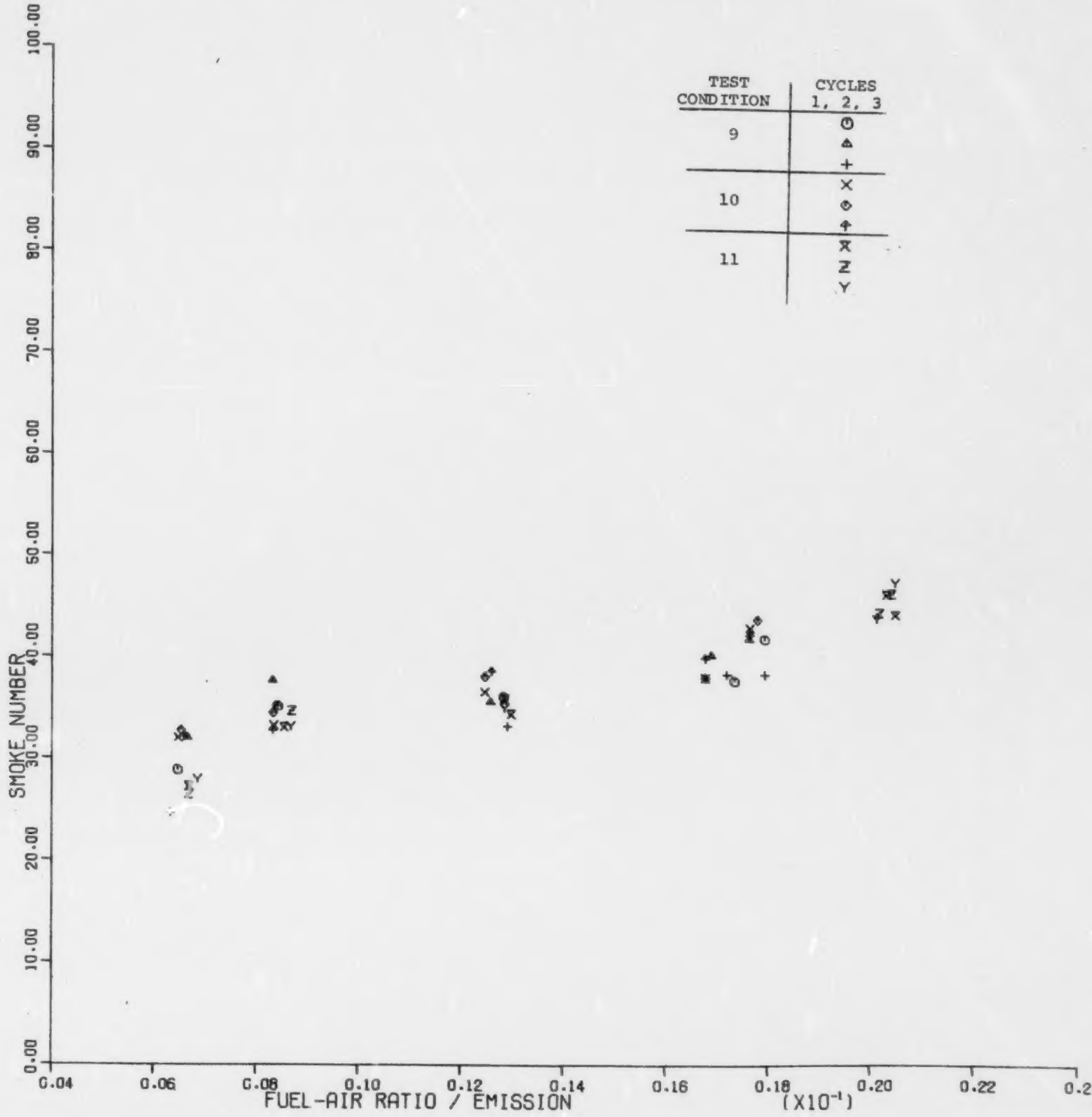
TEST CONDITIONS 9.10.AND 11

FIGURE 4-2



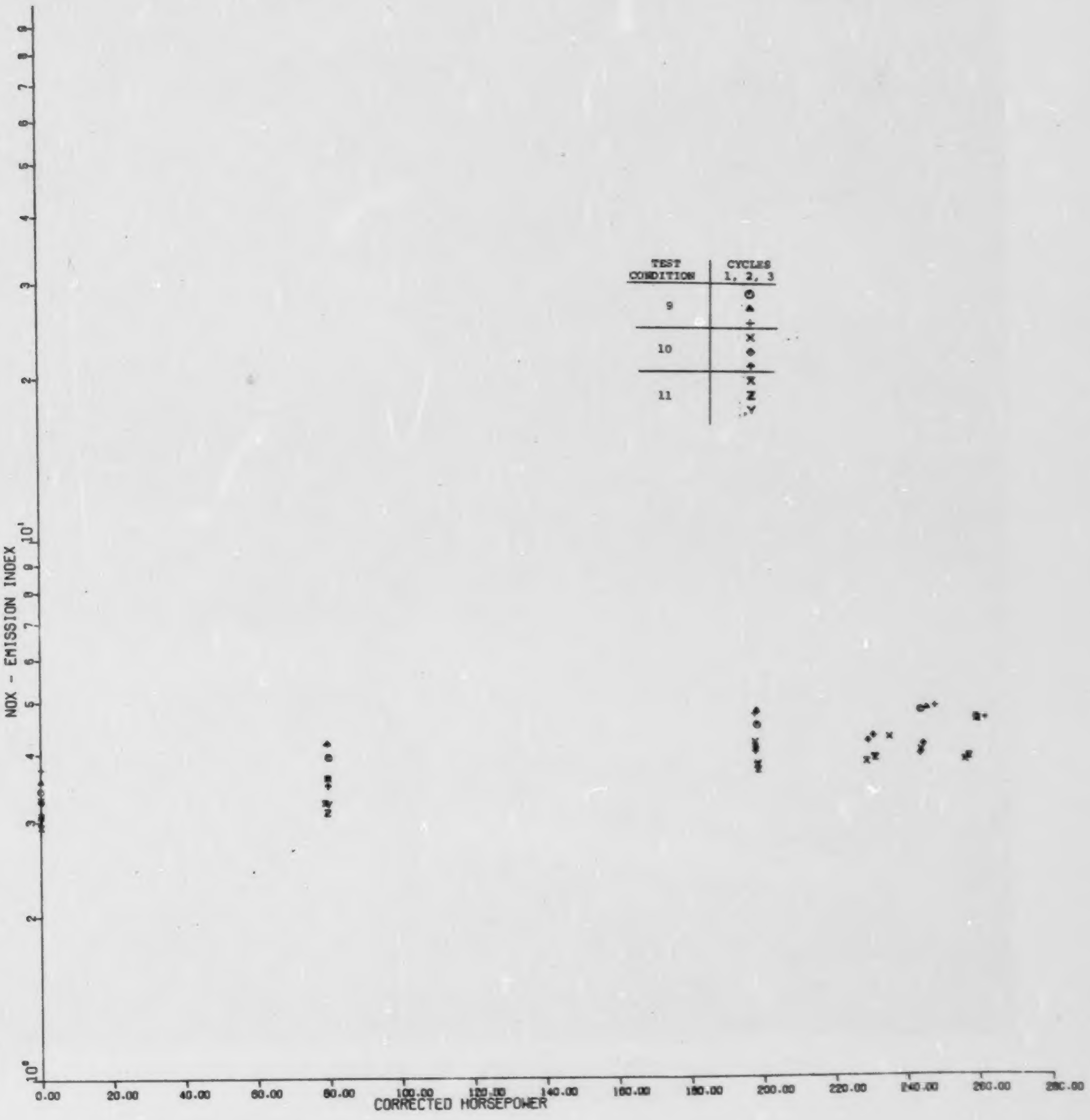
TEST CONDITIONS 9.10.AND 11

FIGURE 4-3



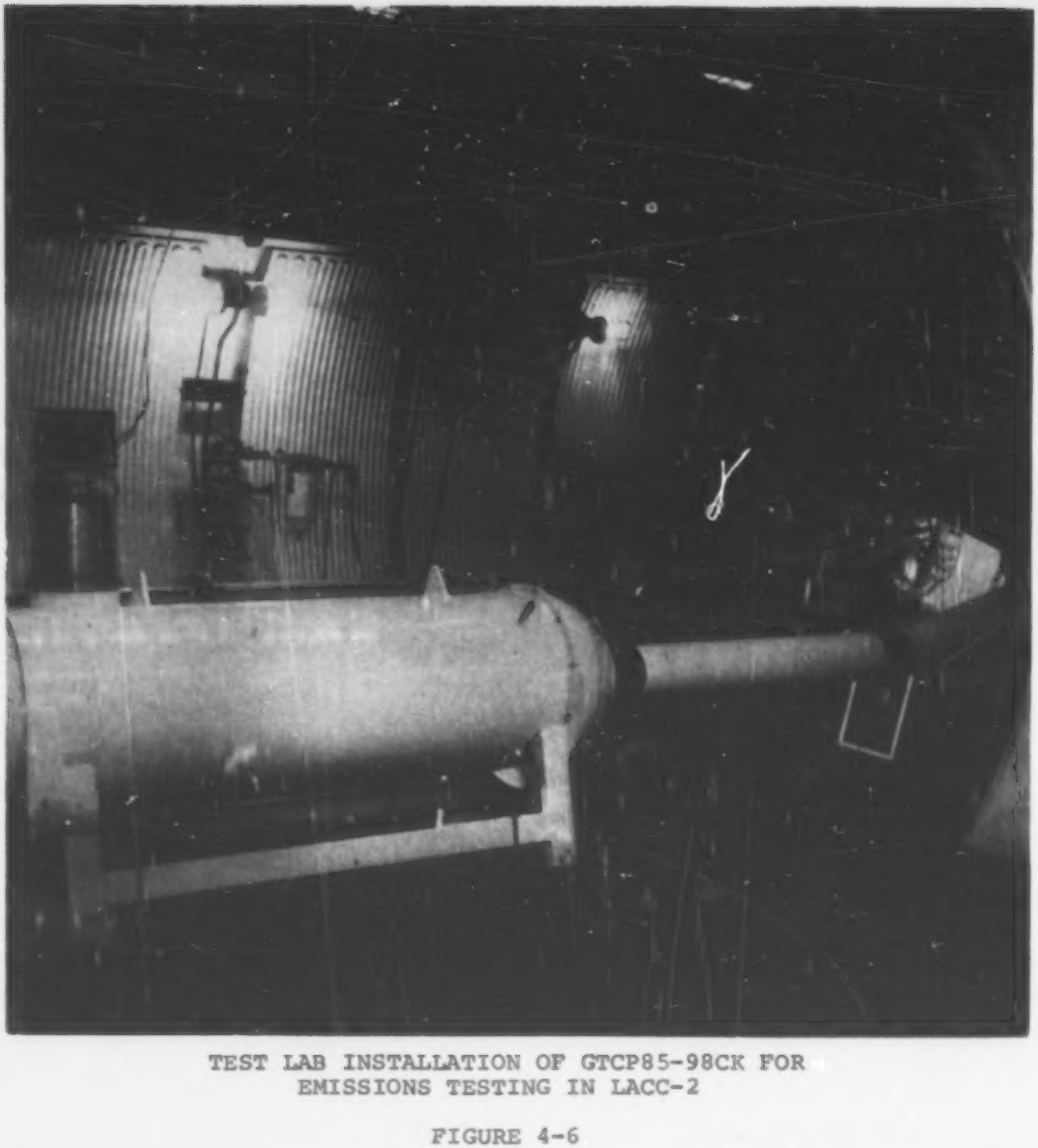
TEST CONDITIONS 9.10.AND 11

FIGURE 4-4



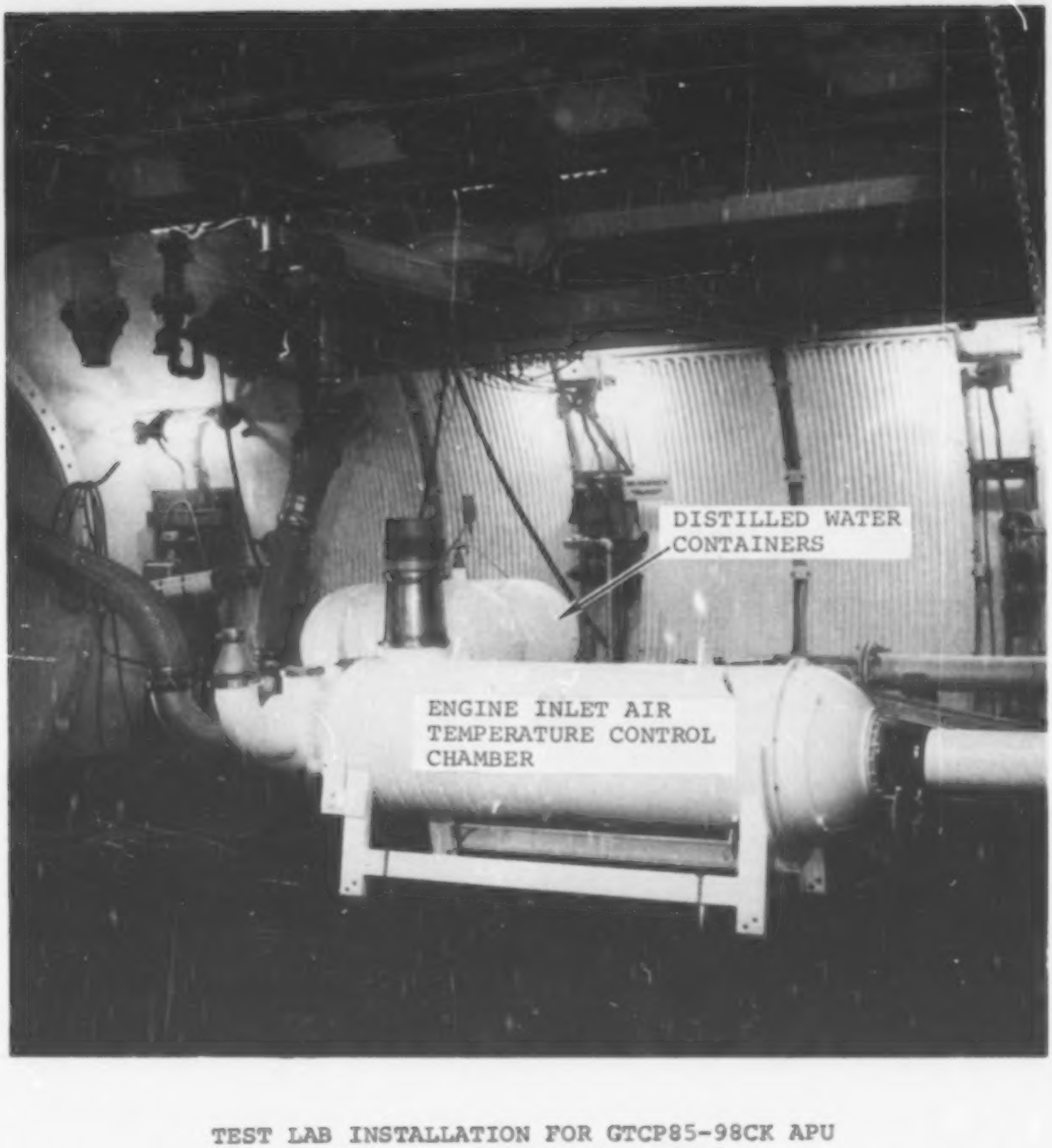
TEST CONDITIONS 9.10.AND 11

FIGURE 4-5



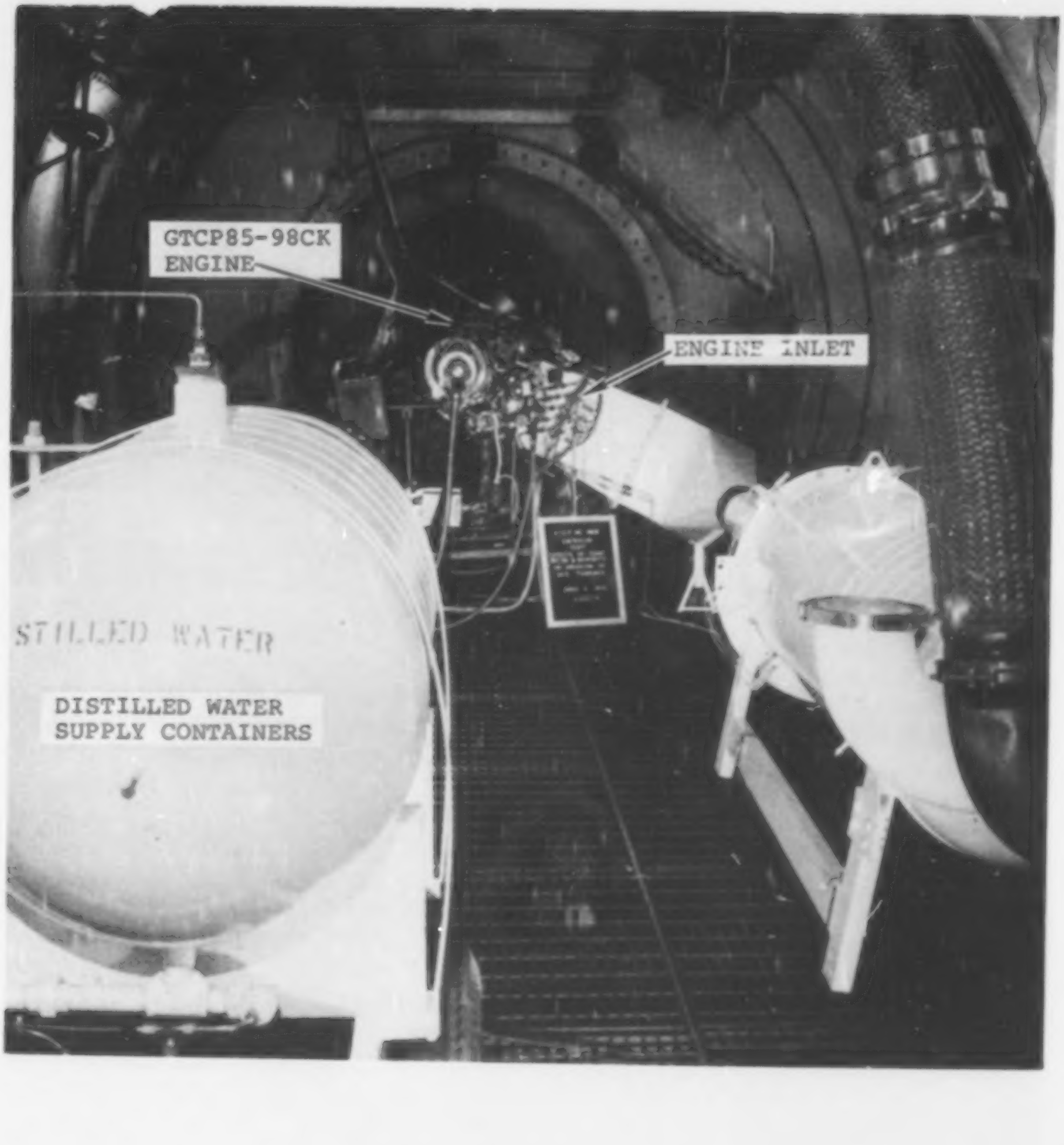
TEST LAB INSTALLATION OF GTCP85-98CK FOR EMISSIONS TESTING IN LACC-2

FIGURE 4-6


DISTILLED WATER CONTAINERS
ENGINE INLET AIR TEMPERATURE CONTROL CHAMBER

TEST LAB INSTALLATION FOR GTCP85-98CK APU
EMISSIONS TESTING IN LACC-2

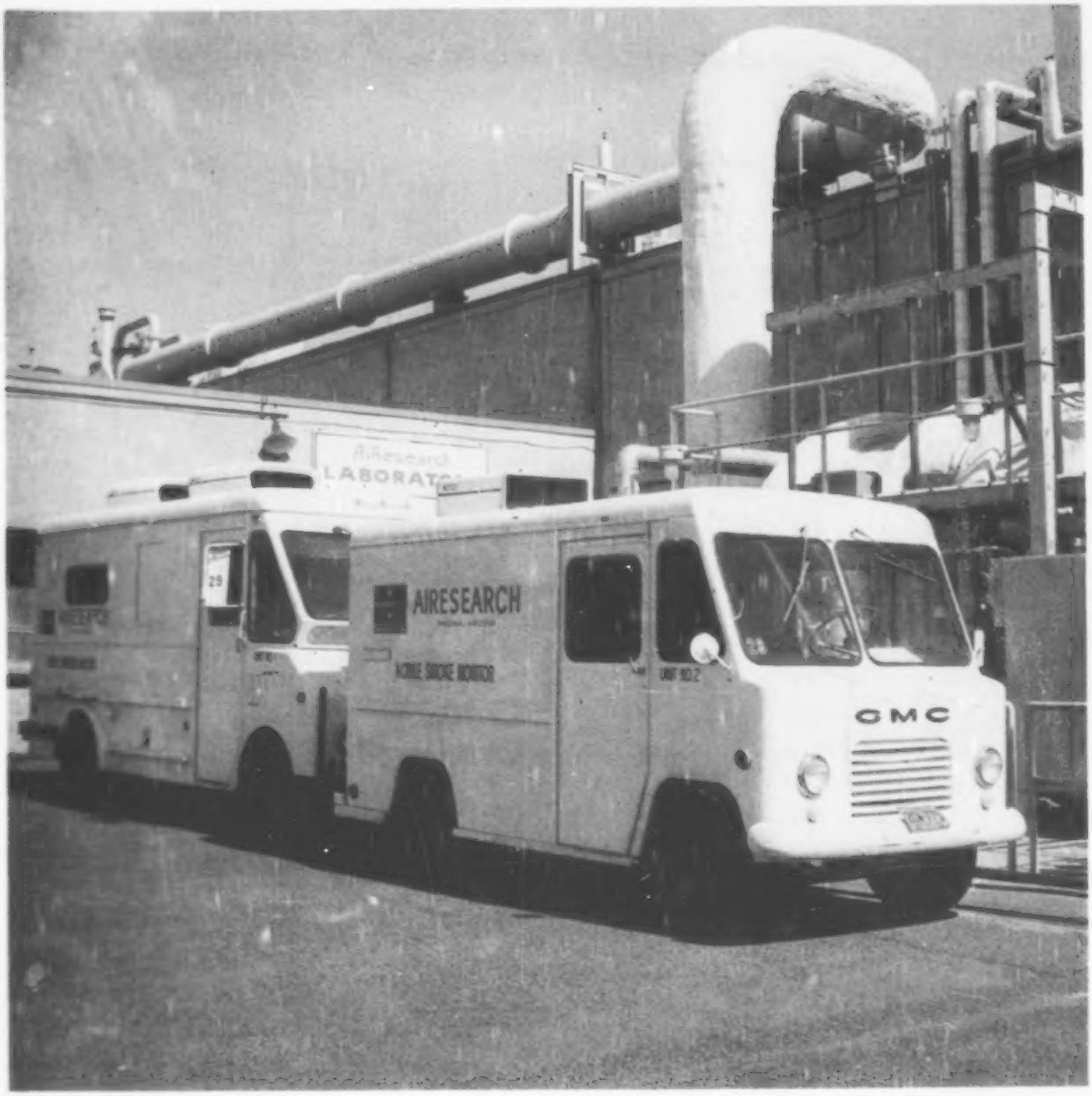
FIGURE 4-7


GTCP85-98CK
ENGINE
ENGINE INLET
STILLED WATER
DISTILLED WATER
SUPPLY CONTAINERS

GTCP85-98CK ENGINE INSTALLED IN LACC-2 FOR EMISSIONS TESTING

FIGURE 4-8

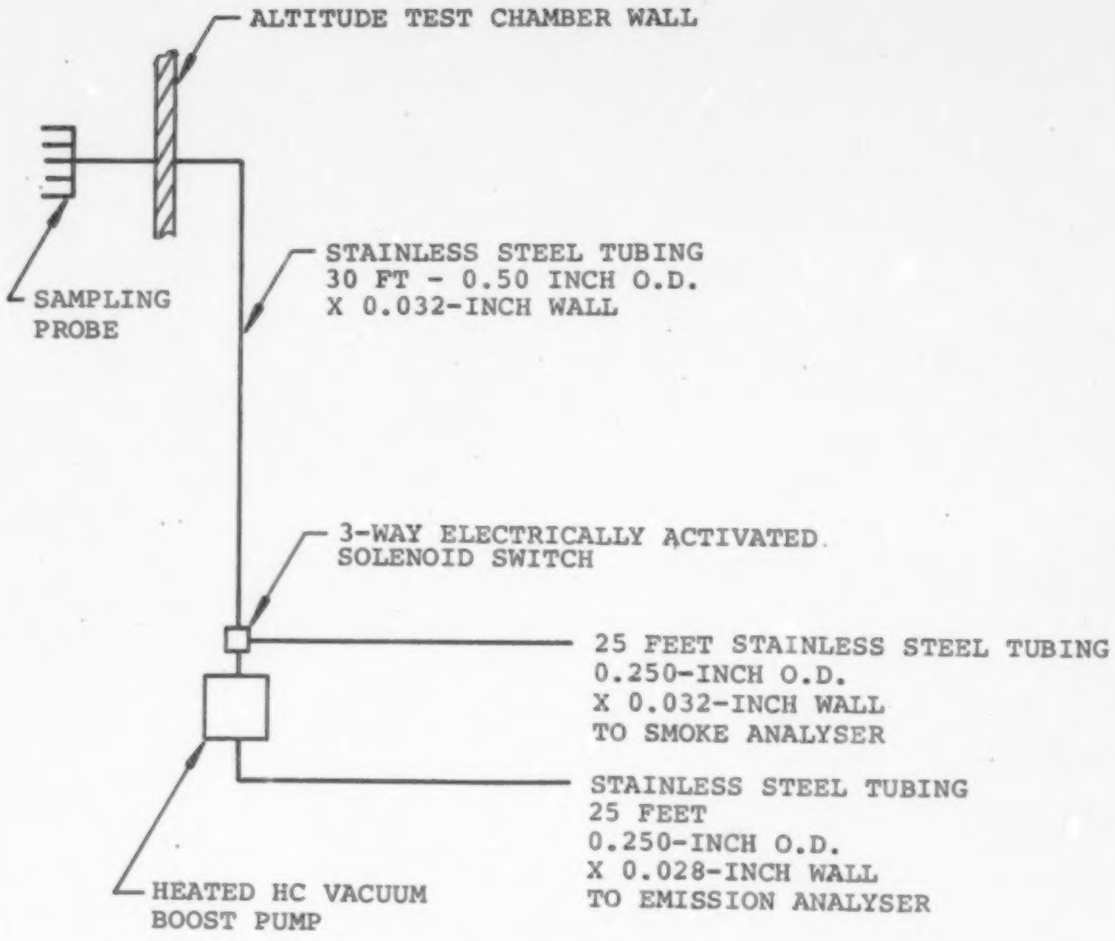
MP-[illegible]


AiResearch
LABORATO
29
AIRESEARCH
MOBILE SMOKE MONITOR
UNIT NO. 2
GMC

EMISSIONS SAMPLING AND MEASURING VANS IN PLACE FOR GTCP85-98CK
EMISSIONS TESTING IN LACC-2

FIGURE 4-9

[illegible]


ALTITUDE TEST CHAMBER WALL
STAINLESS STEEL TUBING
30 FT - 0.50 INCH O.D.
X 0.032-INCH WALL
SAMPLING
PROBE
3-WAY ELECTRICALLY ACTIVATED
SOLENOID SWITCH
25 FEET STAINLESS STEEL TUBING
0.250-INCH O.D.
X 0.032-INCH WALL
TO SMOKE ANALYSER
STAINLESS STEEL TUBING
25 FEET
0.250-INCH O.D.
X 0.028-INCH WALL
TO EMISSION ANALYSER
HEATED HC VACUUM
BOOST PUMP

EMISSIONS SAMPLE LINE SYSTEM

FIGURE 4-10

A list of instrumentation for which readings were recorded is presented in Table 4-4. Additional instrumentation for monitoring engine internal conditions, such as vibration, air temperature and pressure, etc., were continuously observed to detect any engine malfunction. These latter instrumentation readouts were not recorded. A sample of data, manually recorded during testing, is shown in Appendix II.

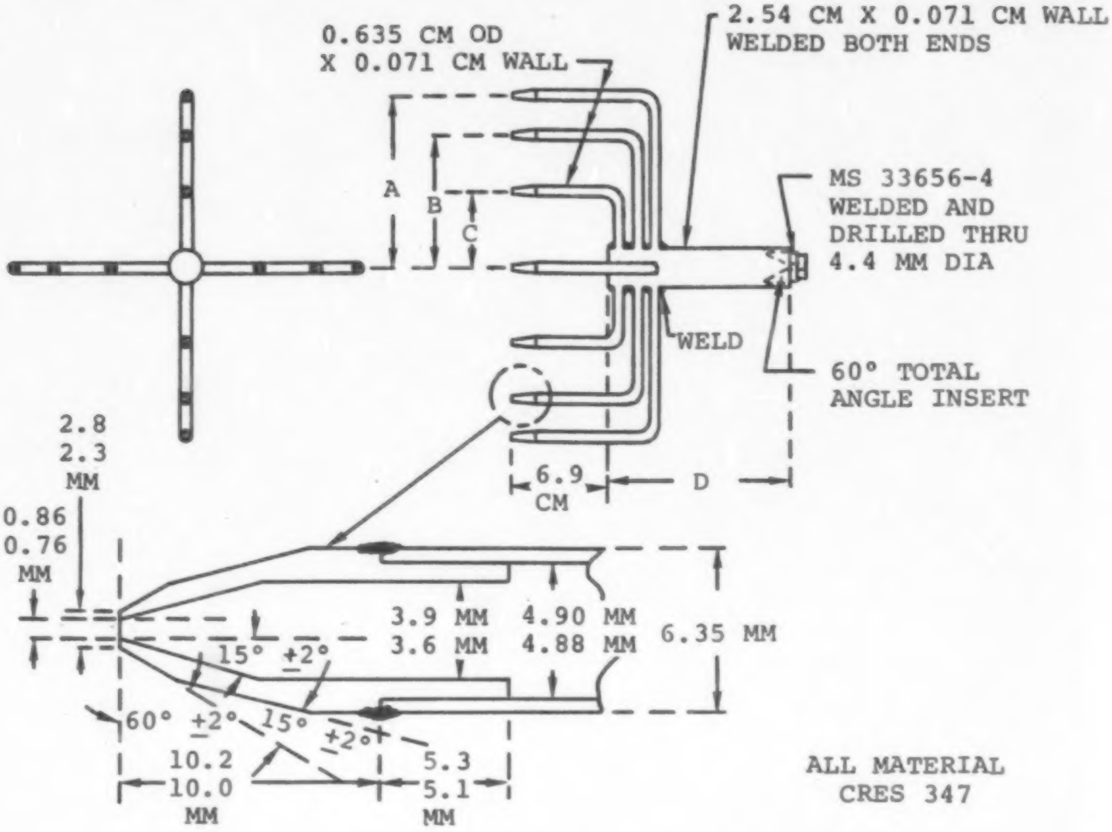
A 12-point uncooled averaging emissions sampling probe, shown in Figure 4-11, was used to sample engine emissions. This probe was designed in accordance with 40 CFR 87. The probe was designed to have the sampling ports at the center of equal areas per blueprint drawing SKP 32566, Appendix III. The probe was attached to the APU exhaust flange, as shown in Figure 4-12. Both gaseous and smoke emissions were taken from this probe.

The GTCP85-98CK test was conducted in a manner that sea-level standard-day corrected horsepower remained constant for each engine load condition over the range of engine ambient conditions. Since engine ambient conditions vary substantially, engine operating characteristics are greatly affected. Therefore, it was necessary to initially determine the most stringent engine ambient condition from a performance standpoint. A computer engine cycle study of the sixteen ambient conditions revealed Condition 12 to be the most severe since the highest exhaust gas temperature resulted at this condition. Since exhaust gas temperature is limited to 1150°F (621.1°C) for the GTCP85-98CK APU, the corrected total horsepower produced at Condition 12 for the two bleed-air load conditions (Condition 5 of Table 4-1) were selected as the constant corrected total horsepower to which all other engine ambient conditions would be tested. Engine load Conditions 1, 2, and 3, being shaft power requirements only, could be run at the corrected levels shown in Table 4-1 because associated exhaust gas temperatures were substantially lower than for the remaining bleed-load conditions.

TABLE 4-4

TEST INSTRUMENTATION DATA
AMBIENT CONDITIONS ON ENGINE EMISSIONS
(GTCP85-98CK)

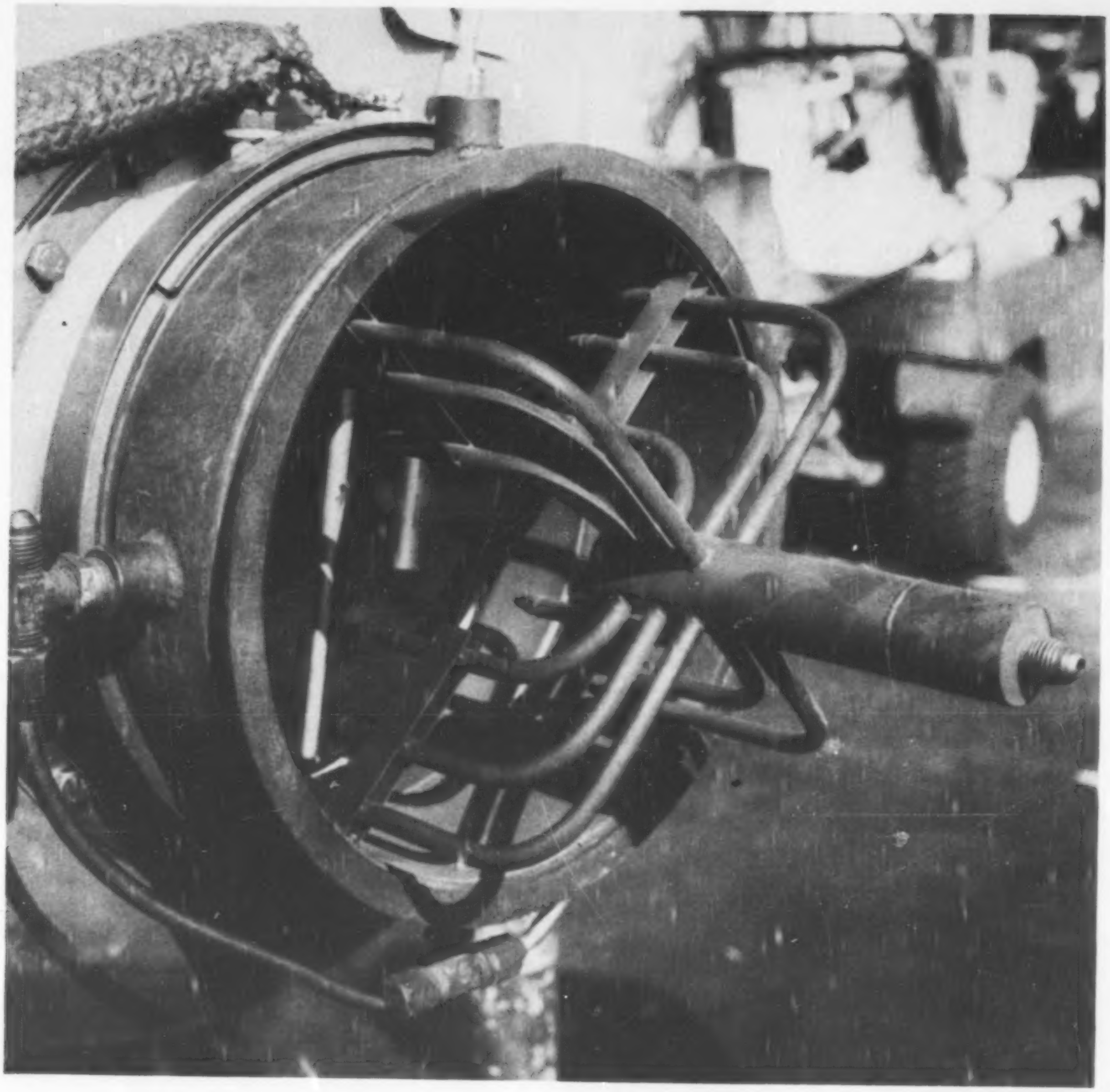
Parameter	Unit	Note
Time	sec:min:hr	
Barometric Pressure	in. Hg abs	
Engine Speed	rpm	
Compressor Inlet Temperature	°F	
Compressor Inlet Total Pressure	in. Hg abs	
Fuel Flow	lb/hr	
Compressor Discharge Pressure	in. Hg G	
Compressor Discharge Temperature	°F	
Exhaust Gas Temperature	°F	(Avg of 8 temperatures)
Exhaust Gas Pressure	in. H_2O	
Engine Torque	in.-lb	
Engine Mass Flow Air:		
Bellmouth Static ΔP	in. H_2O	
Bellmouth Total	in. Hg abs	
Bellmouth Inlet Temperature	°F	
Bleed-Air Temperature	°F	
Bleed-Air Pressure	in. Hg G	
Engine Bleed Flow Air:		
Bleed Orifice Pressure	in. Hg G	
Bleed Orifice ΔP	in. H_2O	
Bleed Orifice Temperature	°F	
Water Flow	gal/hr	
Sample Line Temperature	°F	(4 temperatures measured)


0.635 CM OD
X 0.071 CM WALL
2.54 CM X 0.071 CM WALL
WELDED BOTH ENDS
A
B
C
MS 33656-4
WELDED AND
DRILLED THRU
4.4 MM DIA
WELD
60° TOTAL
ANGLE INSERT
2.8
2.3
MM
6.9
CM
D
0.86
0.76
MM
3.9 MM
3.6 MM
4.90 MM
4.88 MM
6.35 MM
15° ±2°
60° ±2°
15° ±2°
10.2
10.0
MM
5.3
5.1
MM
ALL MATERIAL
CRES 347

DIMENSION	SKP32566-2 GTCP85-98CK	SKP32566-1 TPE331-30-303
A (mm)	93.0	110.0
B (mm)	72.0	84.0
C (mm)	41.0	45.0
D (mm)	128.0	128.0

TWELVE-POINT AVERAGING PROBE

FIGURE 4-11



12-POINT UNCOOLED EMISSIONS SAMPLING PROBE
INSTALLED ON GTCP85-98CK

MP-52007

FIGURE 4-12

4.2 TPE331 Turboprop Combustion Rig Testing

The EPA 1979 aircraft and aircraft engine emissions standards provided the stimulus for AiResearch to investigate other turboprop engine fuel management systems to achieve compliance. In 1973, investigations of various fuel management systems were conducted as part of an extensive IR&D Program to develop techniques for emission control. As a result of this study, a fuel management system was developed that permits engine idle, and near idle, operation on the existing 5 primary fuel atomizers only (with the 10 secondary fuel atomizers shut down). This operational mode, referred to as "primaries only", increases engine idle combustor efficiency resulting in lower HC and CO emission levels. Because initial test results were favorable, this sytem is expected to be incorporated in future TPE331 turboprop engines; and, for this reason, the fuel management system ("primaries only") was selected for further investigation in this test program.

Therefore, turboprop combustion rig supplemental testing was incorporated into the program to assess the following:

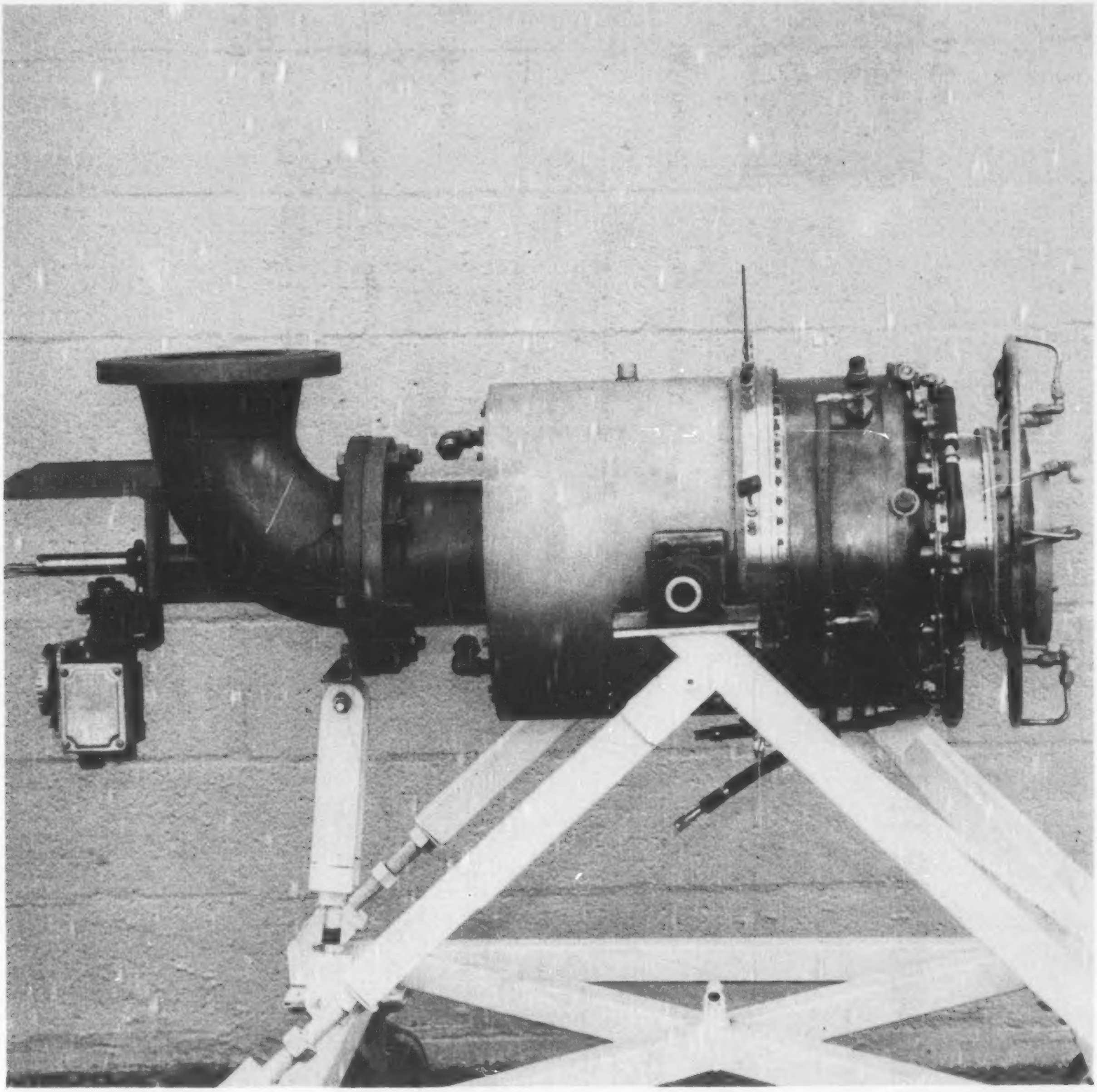
- That "primaries only" operation did not adversely affect combustion durability.
- That "primaries only" operation did not adversely affect combustion discharge temperature profiles that could damage turbine stator vanes.
- Verify that "primaries only" operation did reduce emission levels below 1979 aircraft engine emissions standards.

Thus, the combustion rig test program would ensure that the "primaries only" system was a viable emission control technique that could be safely used in the TPE331 turboprop engine scheduled for this emissions measurement test program.

An available TPE331 combustion rig, shown in Figure 4-13, was refurbished for this test program with production combustion system hardware installed. The combustion rig was installed in the AiResearch-Phoenix combustion test cell. A typical combustor test rig cross-section is shown in Figure 4-14. Rig inlet temperature is controlled by pre-mixing hot and cold air upstream of the rig. Airflow is then directed through an orifice section to measure airflow, and rig pressure is controlled by a valve downstream of the rig. The airflow specific humidity, delivered to the rig, is essentially dry at 0.00071 lb of H_2O/lb of dry air.

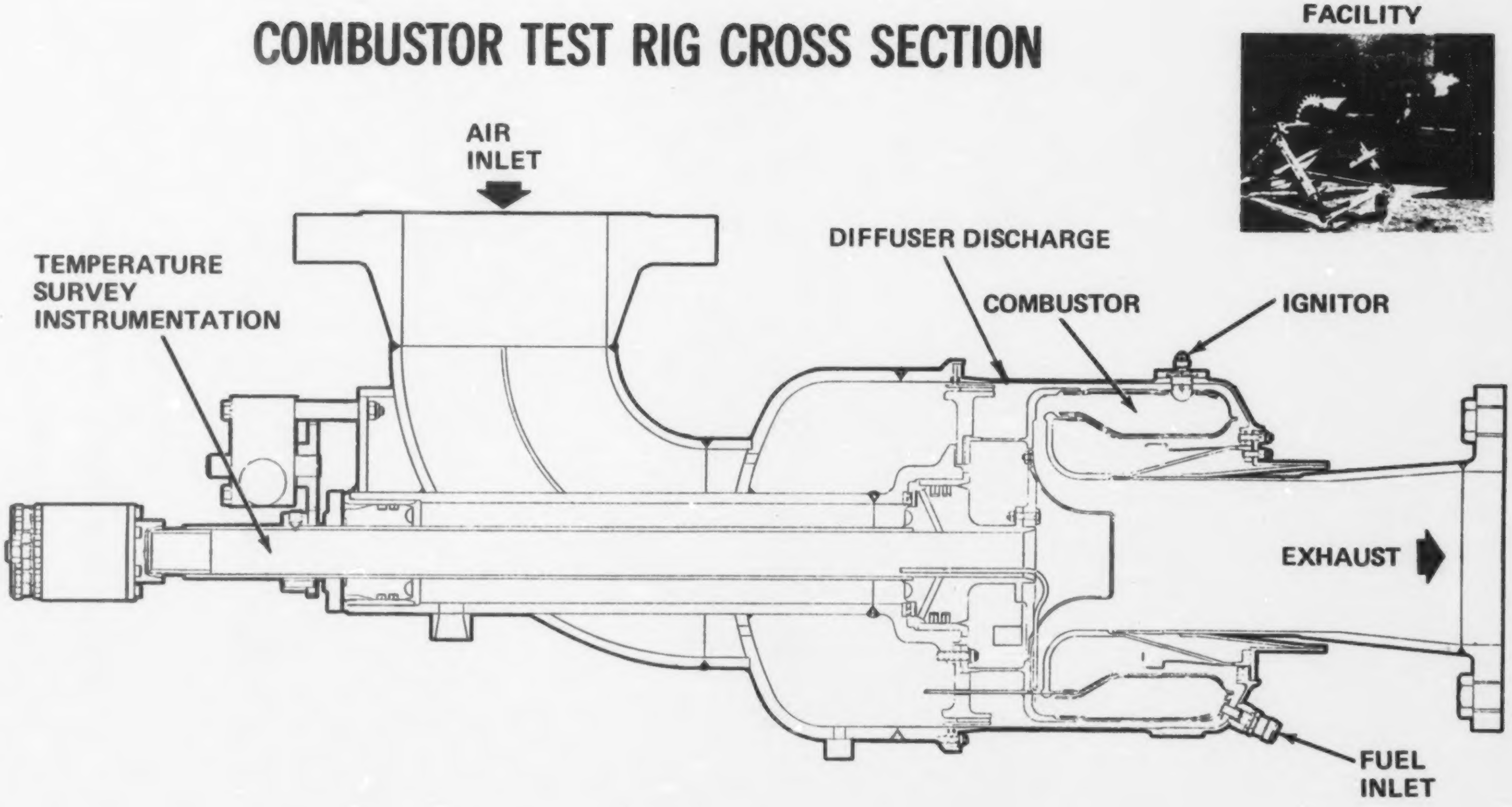
Combustion rig instrumentation used during testing includes measured data listed in Table 4-5. A sample of data recorded during testing is presented in Appendix II. The emissions sampling probe for this test consisted of three equally spaced fixed probes located downstream of the discharge duct mixing baffle. The three probes were manifolded together in the exterior of the rig and a single heated line delivered the sample to the emission analyzing equipment described in Section 3.2. Each probe had two sampling ports spaced one inch apart, with no port located closer than one inch from the discharge duct wall.

Combustor discharge temperatures were measured with a 7-element, 24-step rotating rake. The rake thermocouples were chromel/alumel type. Thermocouple readings were automatically recorded on computer paper tape, which was converted to standard computer card format for combustor performance data reduction. All inlet conditions were manually recorded from multiple circumferential and radial positions at the compressor diffuser duct exit.



TPE331 COMBUSTION SYSTEM TEST RIG

FIGURE 4-13


COMBUSTOR TEST RIG CROSS SECTION
FACILITY
AIR INLET
TEMPERATURE SURVEY INSTRUMENTATION
DIFFUSER DISCHARGE
COMBUSTOR
IGNITOR
EXHAUST
FUEL INLET

COMBUSTOR TEST RIG FACILITY
FIGURE 4-14

TABLE 4-5

TPE331 COMBUSTION RIG TEST INSTRUMENTATION

Parameter	Unit	Note
Barometer	in. Hg A	
Air Orifice Inlet Pressure	PSIG	
Air Orifice Inlet Temperature[29]	°F	
Air Orifice ΔP	in. H_2O	
Combustor Inlet Static Pressure	in. Hg G	
Combustor Inlet Total Pressure	in. Hg G	2 Readings
Combustor Inlet Total Temperature	°F	2 Readings From Rotating Rake
Combustor Discharge Static Pressure	in. Hg G	
Fuel Pressure	PSIG	
Fuel Flow	lb/hr	Measured by rotometer
Rig Rake Temperature	°F	7 Readings From Rotating Rake At Top Dead Center

A baseline test of the normal fuel management system (primary plus secondary fuel atomizers) based on TPE331-3U-303 engine rated condition (840 horsepower corrected to sea level, 59°F day) was performed at the test operating conditions listed in Table 4-6. Rig operating conditions for this test were determined from a TPE engine computer performance cycle program. Operating conditions listed in Table 4-6 represented the most severe engine ambient operating conditions expected in service from the range of ambient test conditions (Table 1-2) conducted during TPE331 engine testing. Engine load conditions corresponding to approach, cruise, climbout, and takeoff were also evaluated to calculate the TPE331 emission levels over the prescribed EPA duty cycle. Each load is some fraction of engine rated 840 horsepower corrected to sea level 59°F day.

The test conditions in Table 4-6 were then repeated for "primaries only" operation. Since these tests were combustor rig tests, required fuel system modifications to allow engine operation on "primaries only", were simulated by disconnecting the 10 secondary fuel atomizers. Test Condition 13 of Table 4-6 was not run because the required fuel pressure exceeded the facility capabilities.

The following information was determined for the two baseline tests:

(a) Gaseous emissions CO, HC, and NO_x

(b) Maximum combustor discharge temperature, T_4max

(c) Average combustor discharge temperature, T_4avg

(d) Combustor discharge pattern factor, PF,

$$PF = \frac{T_{max} - T_{avg}}{T_{avg} - T_{in}}$$

(e) Fuel-air ratio determined by measurement and by calculation from emissions

TABLE 4-6

TPE331 OPERATING CONDITIONS

Verification Test Points for Operation Using Primary Fuel Atomizers Only				
Test Point	To (^{o}C)	Po (mm)	Power Set	Humidity
1	15	740 (or 760)	Idle	Hold constant for each test point
2	↓	↓	1.5 x Idle	↓
3	↓	↓	2.0 x Idle	↓
4	↓	↓	Approach (30%)	↓
5	↓	↓	Cruise (70%)	↓
6	↓	↓	Climbout (90%)	↓
7	↓	↓	Take-off (100)	↓
8	↓	500	Idle	↓
9	↓	↓	1.5 x Idle	↓
10	↓	↓	2.0 x Idle	↓
11	-7	740	Idle	↓
12	↓	↓	1.5 x Idle	↓
13	↓	↓	2.0 x Idle	↓
14	33	740	Idle	↓
15	↓	↓	1.5 x Idle	↓
16	↓	↓	2.0 x Idle	↓

(f) Combustion efficiency, calculated from emissions

(g) Landing Take-Off (LTO) emission levels for sea level standard day conditions

Because of a requirement to maintain constant corrected horsepower during TPE331 engine emissions sampling, a derated power output was necessary to prevent turbine interstage overtemperature. Therefore, a TPE331 engine performance computer model was used to analyze the ambient test conditions of Table 4-2.

The most severe performance condition, of those listed, was Condition 12, where the allowable actual horsepower was calculated to be 728 shaft horsepower (shp) for the 100 percent takeoff power setting. When corrected to sea level standard day conditions, this value becomes 706 shp. This 706 shp value permits testing over the entire range of Table 4-2 conditions without exceeding turbine interstage temperature limitations.

In conjunction with the corrected 706 shp value, all remaining power settings were calculated as a percentage of this power level. Actual horsepower for all other ambient test conditions of Table 4-2 were calculated such that the sea level corrected value (706 shp) remained constant. Results of these calculations are presented in Table 4-7.

To evaluate effects of the new engine load conditions on combustor performance, the TPE331 combustor was tested (as in the previous case) for the new conditions listed on Table 4-7. The operating points of Table 4-7 were tested with rig conditions being determined for a constant 706 corrected shaft horsepower. All testing was conducted with dry air.

TABLE 4-7

TURBOPROP ACTUAL POWER SETTINGS FOR WHICH ENGINE PERFORMANCE WAS CALCULATED TO OBTAIN COMBUSTOR RIG TEST INFORMATION**

			POWER SETTING, SHP						
Test Conditions (Table I)	Pressure PSIA	Temp °F	Takeoff 100%	Climbout 90%	Cruise 70%	Approach 30%	2.0 Idle 10% N=65%	1.5 Idle 7.5% N=65%	Idle 5% N=65%
1-2*	14.696	19	678	610	475	203	68	51	34
3-4*	14.696	39	692	623	484	208	69	52	35
5-8*	14.696	59	706	635 635.4	494 494.2	212 211.8	71 70.6	53 52.95	35 35.3
9-12*	14.696	91	728	655	510	218	73	55	36
13	11.21	59	539	485	377	162	54	40	27
14	12.76	59	613	552	429	184	61	46	31
15	14.31	59	687	618	481	206	69	52	34
16	9.67	59	465	419	326	140	47	35	23

* These conditions have varying specific humidities, but this has little effect on overall engine performance.

** The actual physical power, shp, shown column listed under each engine load condition, reflects the corrected shaft horsepower, $shp/\sqrt{\theta}\delta$ of test conditions 5 - 8, that is maintained constant over the range of ambient test conditions.

4.3 TPE331 Turboprop Engine Testing

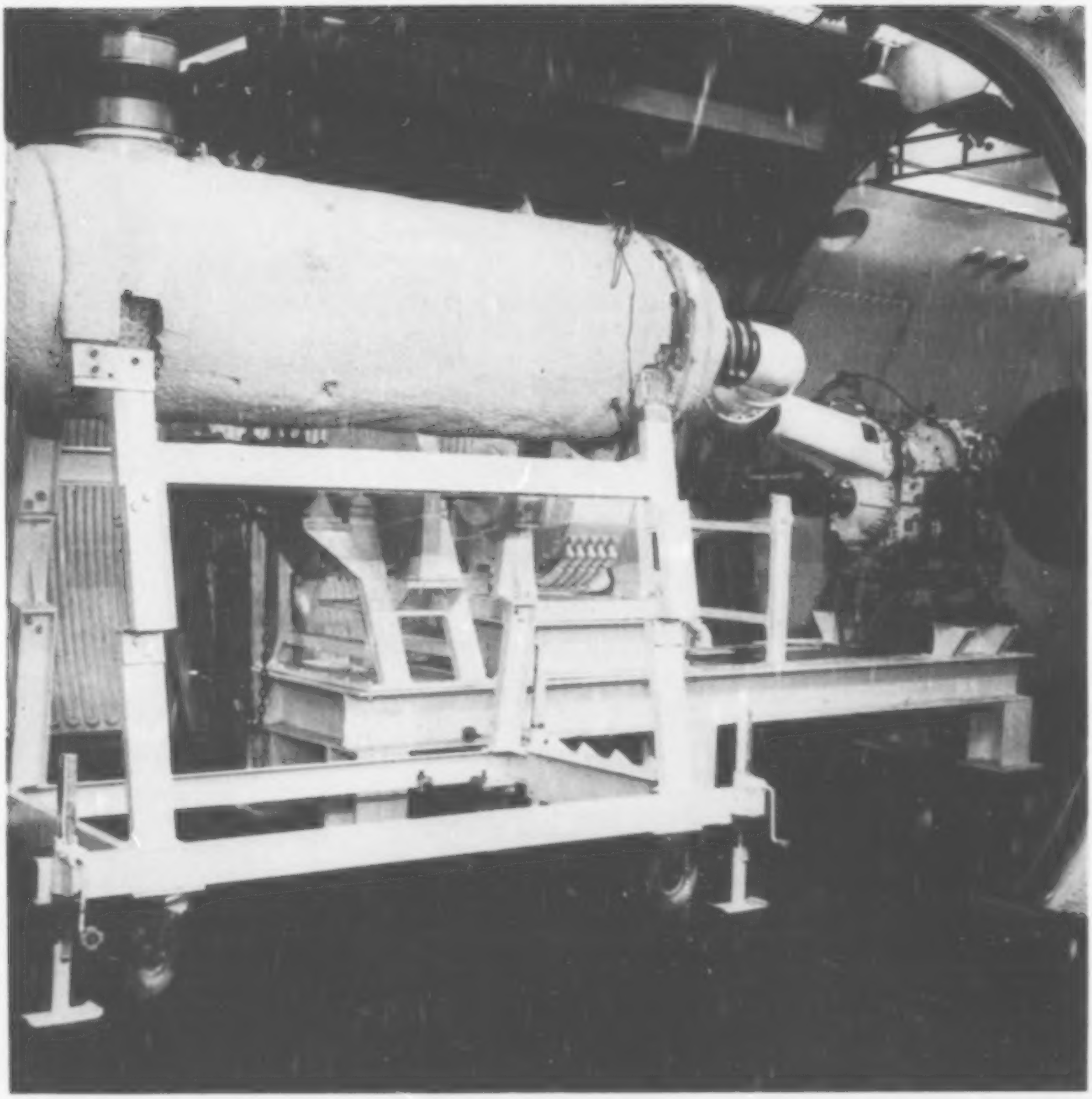
4.3.1 TPE331-3U-303 Engine Test Installation

TPE331-3U-303 turboprop engine, S/N 00304, was installed in the Large Altitude Test Chamber (LACC-2) on October 6, 1975. Test cell engine installation photographs are presented in Figures 4-15, 4-16, and 4-17. Figure 4-18 shows the distilled water supply installed in test chamber.

During initial TPE331-3U-303 installation checkout tests, a support test equipment failure occurred, which resulted in an engine malfunction. Subsequent engine examination disclosed considerable rotating group damage. It was estimated that a minimum of three weeks would be required to repair the damage. In an effort to expedite the test schedule, engine Model TPE331-5-251M, which has the same combustion system and internal aerodynamic configuration (compressor and turbine section), was selected and used as a replacement for the damaged TPE331-3U-303 engine. The TPE331-5-251M and TPE331-3U-303 engines have the same thermodynamic cycle performance and, therefore, required no test program changes. The major differences between the TPE331-5-251M and the TPE331-3U-303 are:

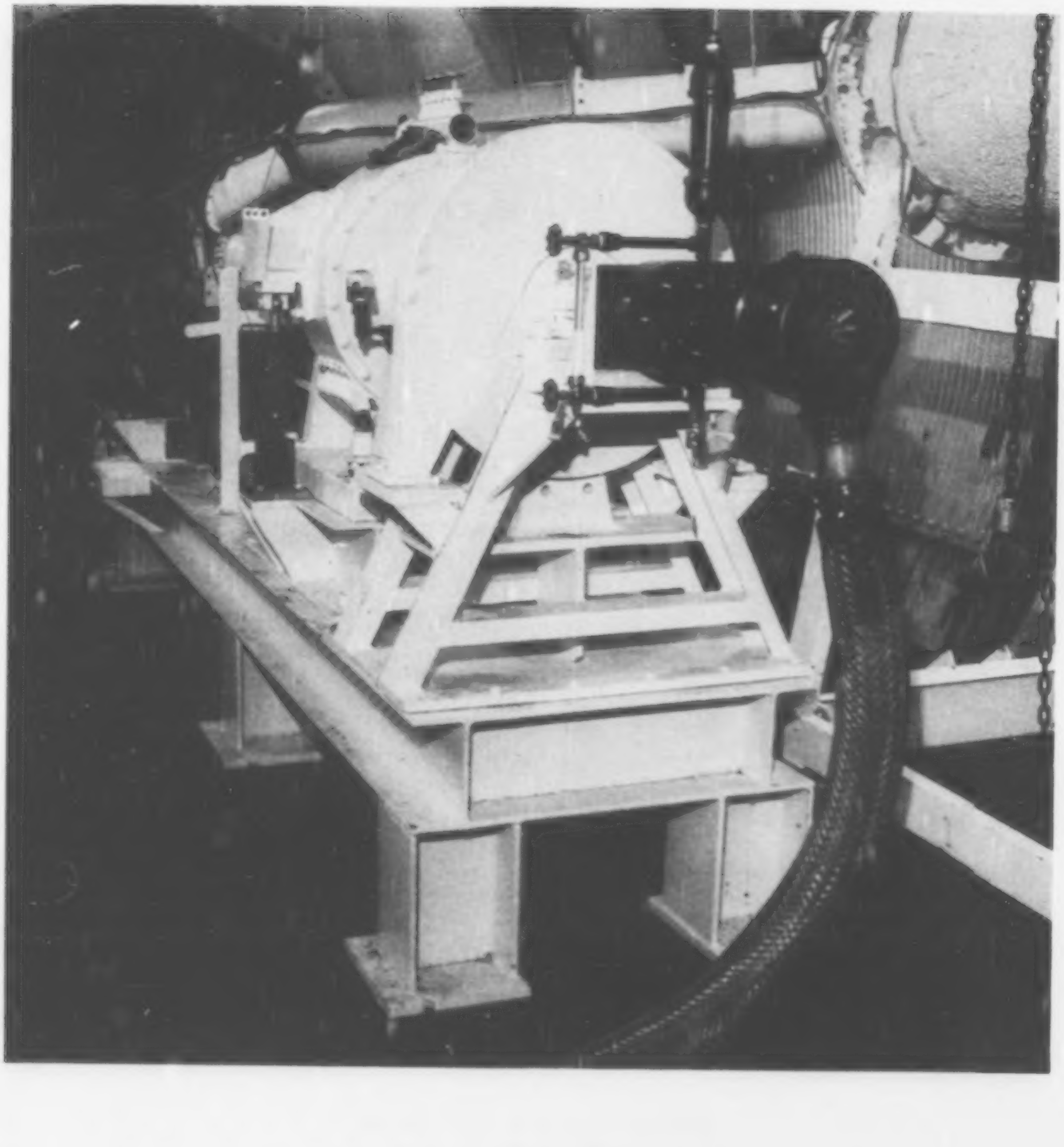
- The replacement engine has a bottom inlet as opposed to a top inlet.
- A different gearbox caused the replacement engine propeller shaft to rotate in the opposite direction.
- The replacement engine gearbox resulted in a lower power rating for a specific customer application.

These differences do not affect engine thermodynamic performance characteristics. All other test installation hardware and instrumentation were identical with the first engine model installation.



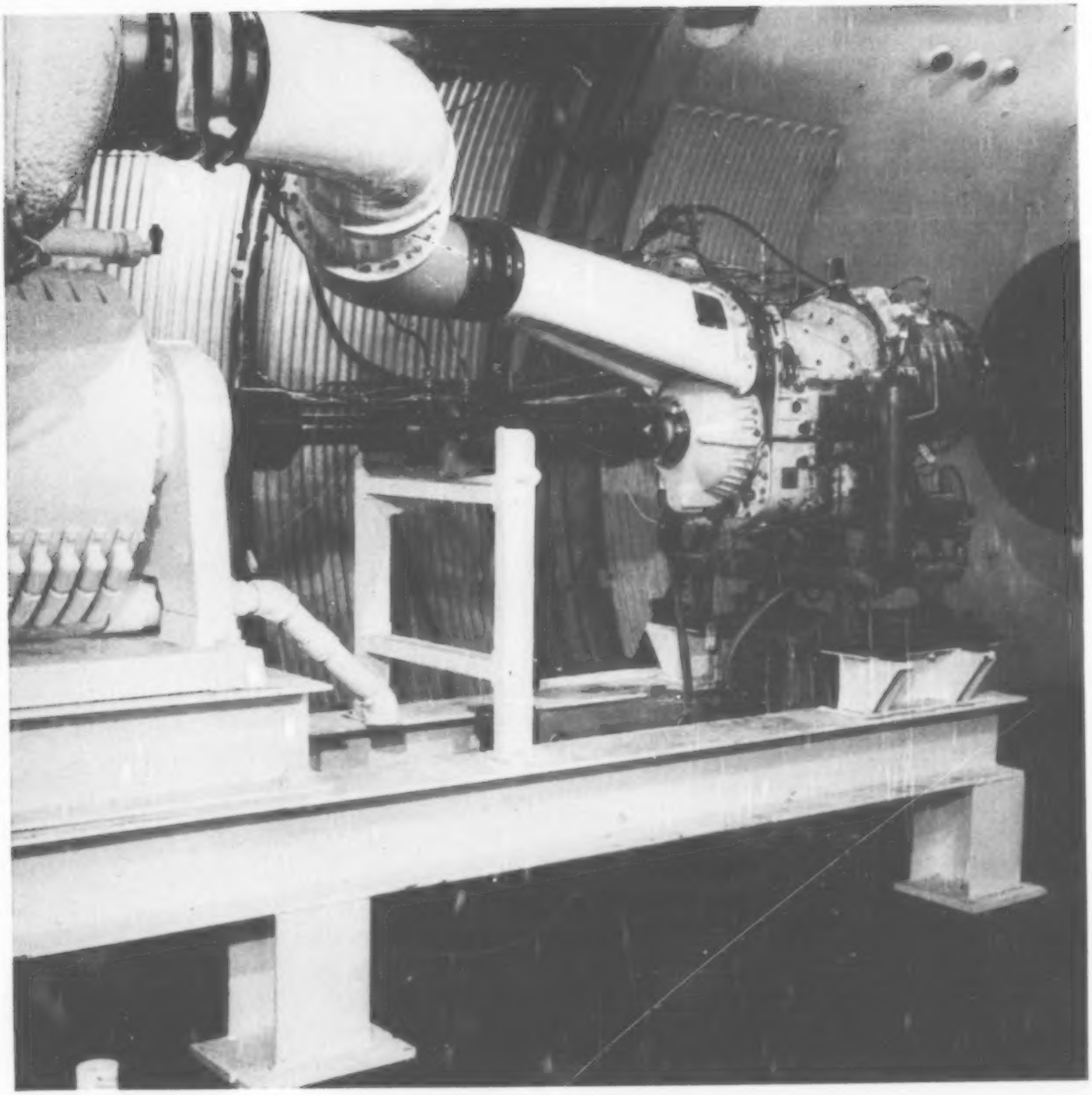
TPE331-3U-303 INSTALLED
IN LACC-2

FIGURE 4-15



TPE331-3U-303 INSTALLED
IN LACC-2

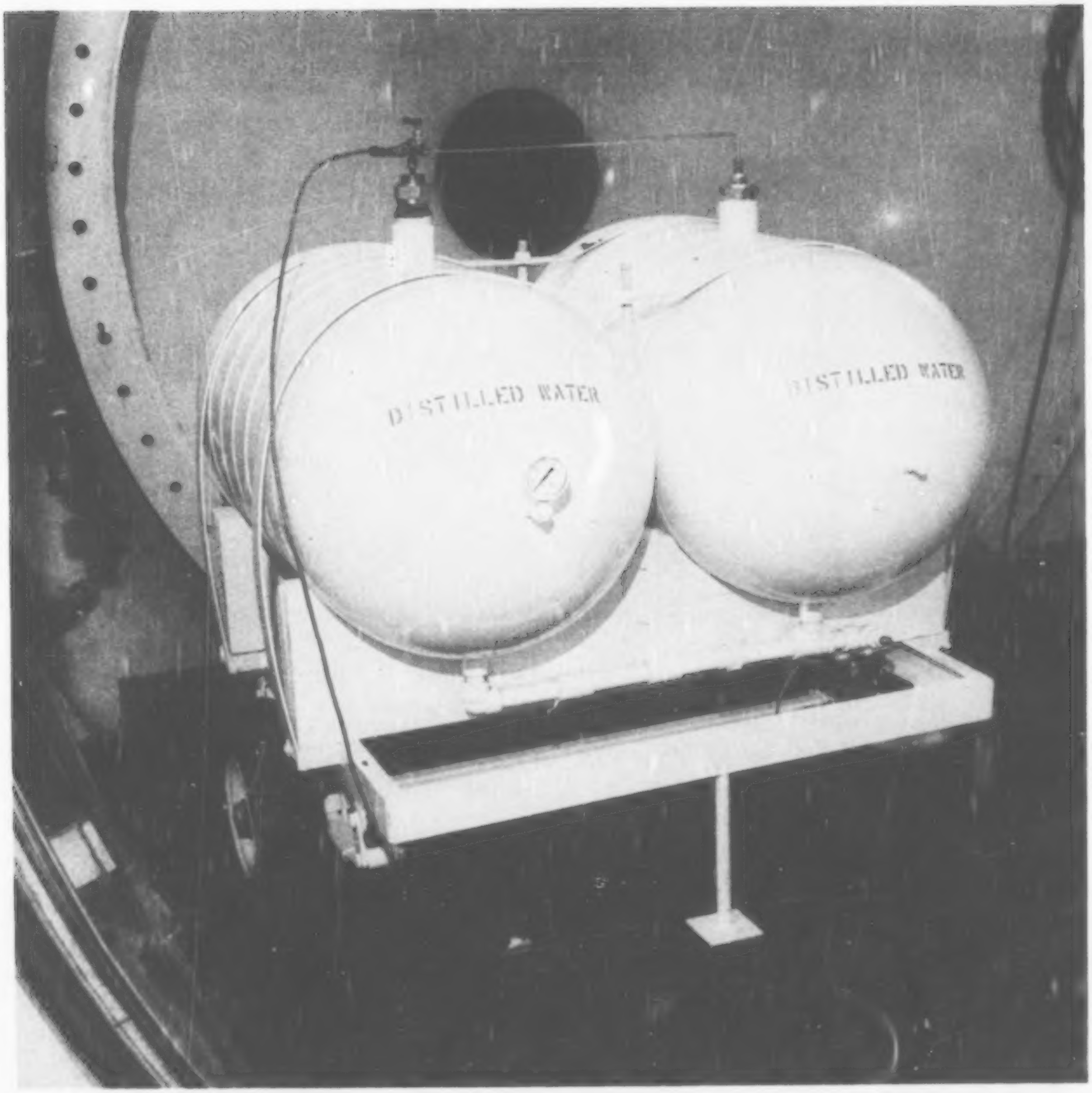
FIGURE 4-16



TPE331-3U-303 INSTALLED
IN LACC-2

FIGURE 4-17

MP-51988


DISTILLED WATER
DISTILLED WATER

DISTILLED WATER SUPPLY INSTALLED
IN LACC-2

FIGURE 4-18

MP-51992

4.3.2 TPE331-5-251M Engine Test Installation

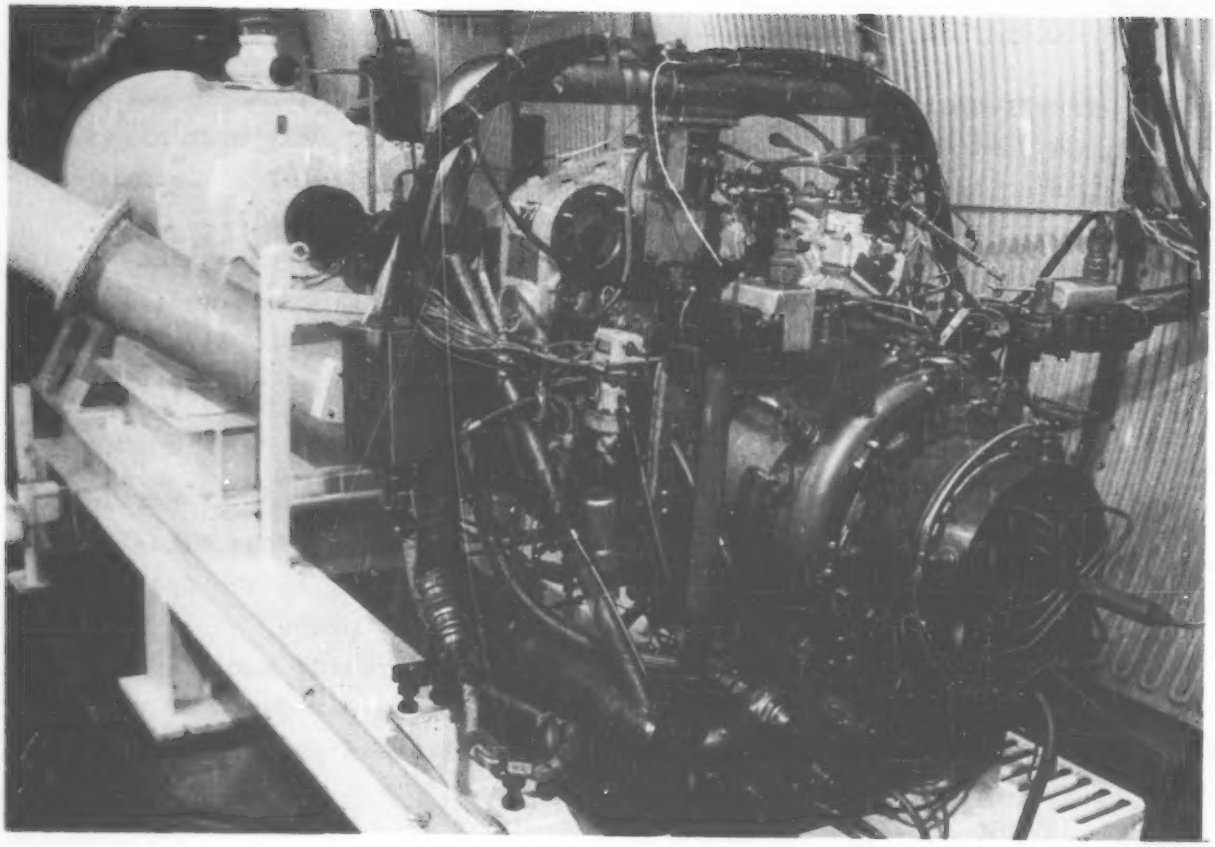
TPE331-5-251M turboprop, S/N 04001, was installed in the Large Altitude Test Chamber (LACC-2) on October 22, 1975. Test installation photographs are presented in Figures 4-19, 4-20, and 4-21. Testing took place during October 25, 1975,-through November 8, 1975. The testing consisted of recording gaseous and particulate emissions levels at the seven engine load conditions listed in Table 4-8, and at each of the 16 ambient test conditions listed in Table 3-2. Three sets of data were required per contract for statistical analysis by Calspan Corporation.

As during the 85 Series APU testing, emission analysis sampling equipment was located directly outside the test cell. The emission sample line system shown in Figure 3-16 is identical to the system described in Section 3.3. The emissions sampling probe, which complies with 40 CFR 87, is a 12-point uncooled averaging sampling probe as shown in the Figure 4-11 schematic. The probe was designed with sampling ports located at the center of equal areas per blueprint drawing SKP32566, Appendix III. Probe installation on the engine is shown in Figure 4-22.

The TPE331-5-251M turboprop was operated at a derated 706 shaft horsepower corrected to sea level 59°F day for the reasons described in Section 4.2. A list of actual shaft horsepower loads, for the seven engine load conditions at each of the 16 ambient test conditions, is presented in Table 4-7.

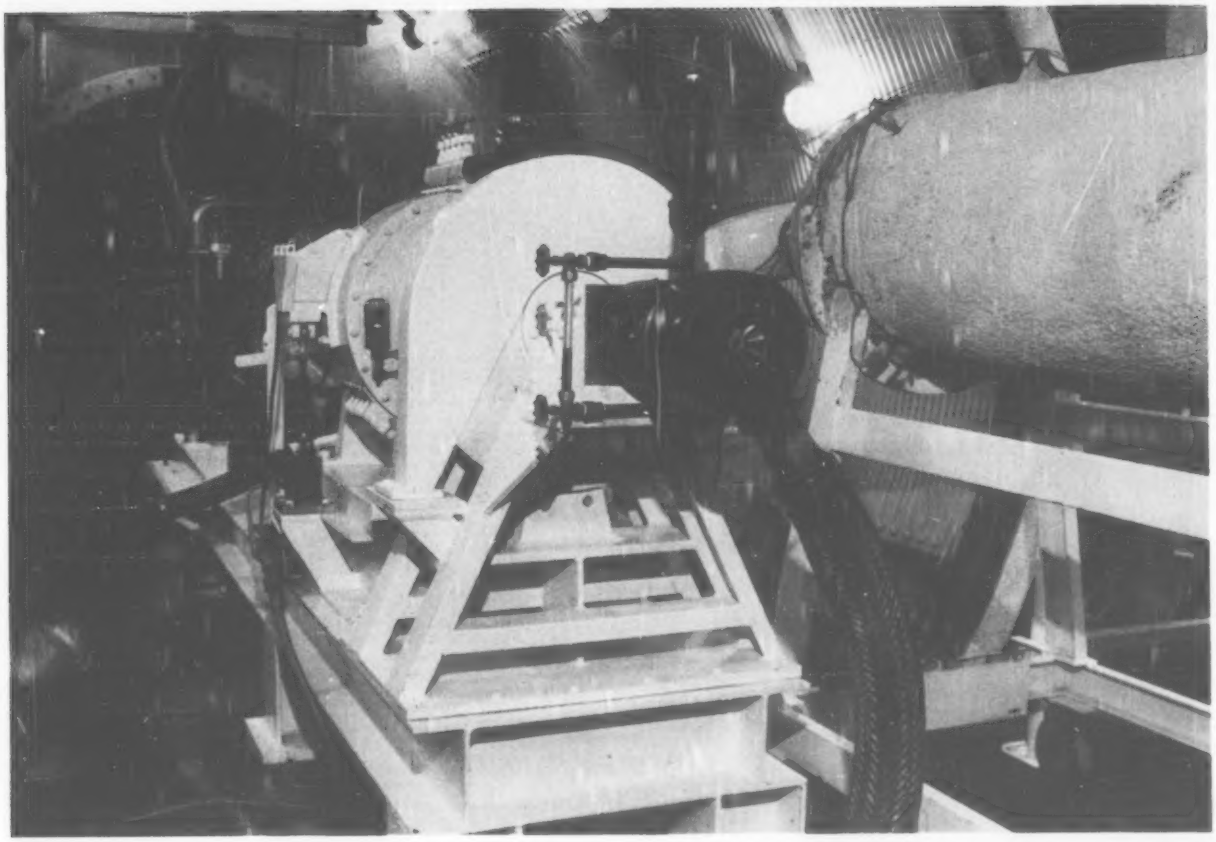
The turboprop was operated at two different engine speeds:

- o Ground idle (27,000 rpm) or output propeller shaft speed of 1050 rpm.
- o Flight speed (41,730 rpm) or output propeller shaft speed of 1591 rpm.



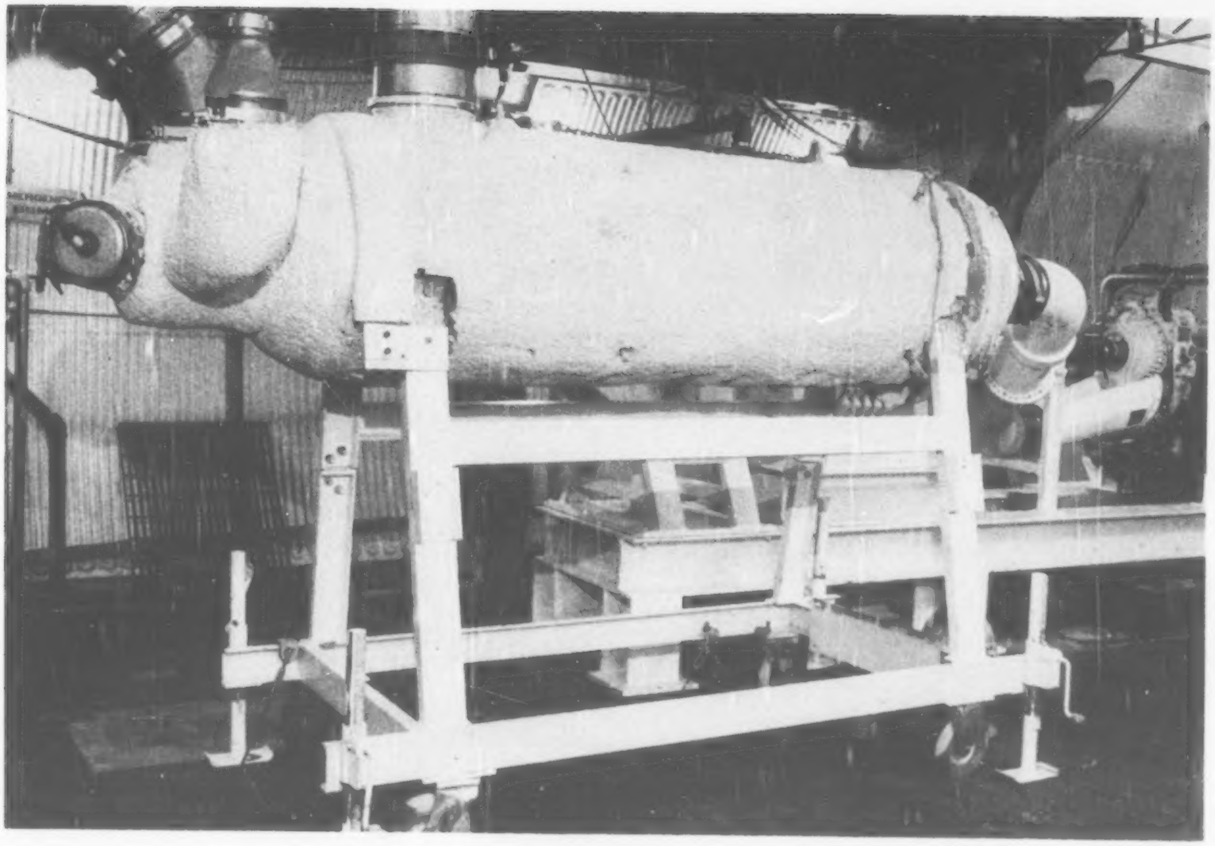
TPE331-5-251M INSTALLED
IN LACC-2

FIGURE 4-19



TPE331-5-251M INSTALLED
IN LACC-2

FIGURE 4-20



TPE331-5-251M INSTALLED
IN LACC-2

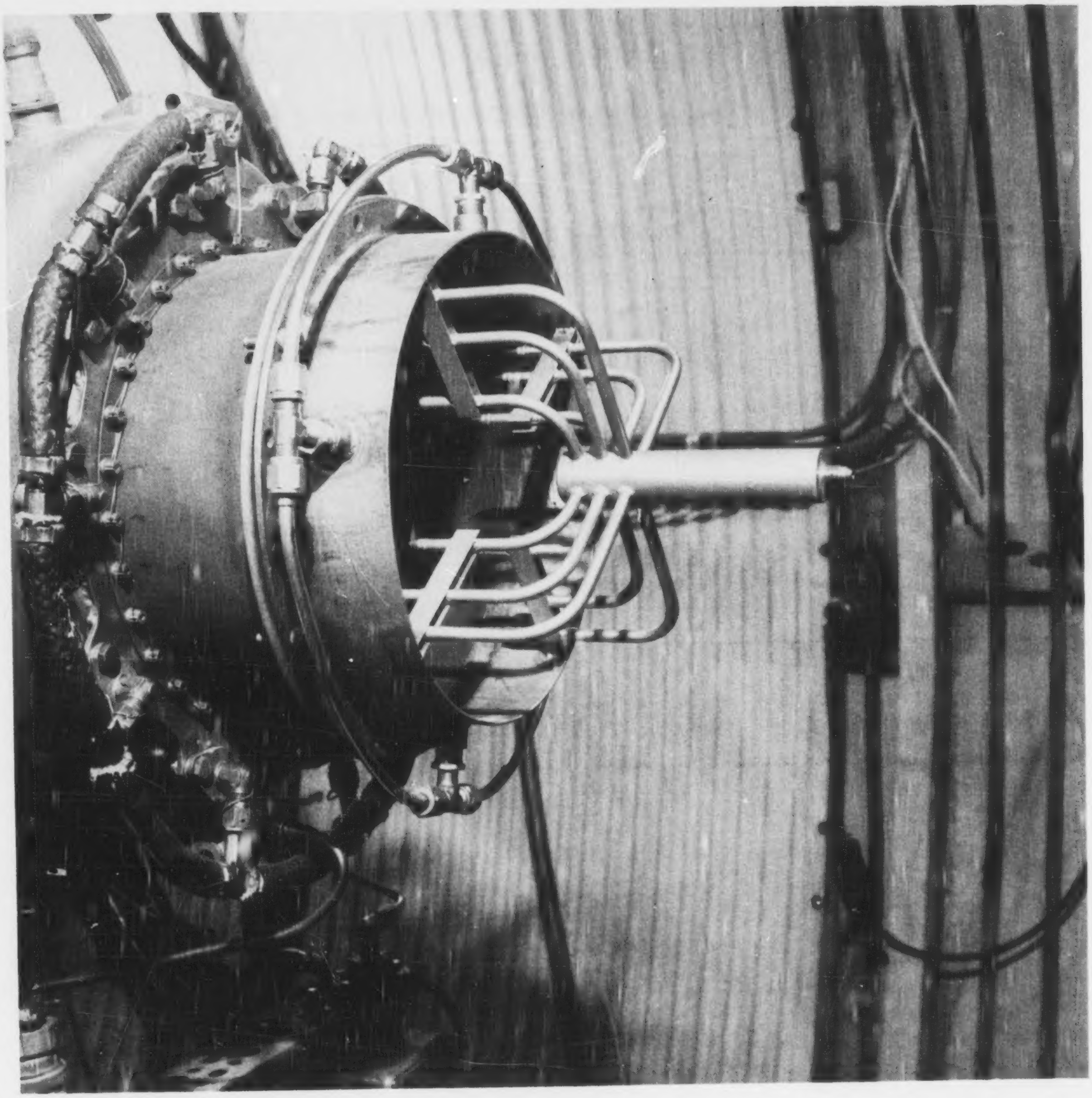
FIGURE 4-21

TABLE 4-8

TPE331 ENGINE LOAD CONDITION

Load Conditions	Power Setting	Power Output (Percent of Derated Power*)	Engine RPM (Percent of Rated RPM)
1**	(Taxi) idle	5	65
2**	1.5 x idle	7.5	65
3**	2.0 x idle	10	65
4	Approach	30	100
5	Cruise	70	100
6	Climbout	90	100
7	Takeoff	100	100

*100% power level is 706 shp/$\sqrt{\theta\delta}$
**Near idle operation on primary fuel atomizer only



12-POINT EMISSIONS SAMPLING PROBE SHOWN INSTALLED ON TPE331 IN LACC-2

FIGURE 4-22

MP-51989

At ground idle speed engine load conditions 1, 2, and 3, the engine was operated on the fuel management system known as "primaries only." This system was utilized to increase idle speed combustion efficiency, thereby reducing CO and HC levels, at the lower engine load condition. A "primaries only" fuel control system schematic for the TPE331 turboprop is shown in Figure 4-23. The normally closed solenoid initiates the "primaries only" mode of operation, on command from the speed lever quadrant taxi switch inside the aircraft cockpit. At engine speeds of 65 percent or less (i.e., taxi, ground idle), the speed lever activates the solenoid to the open position. In this configuration the "primaries only" circuit shunts the fuel metering orifice, thereby reducing differential pressure across the flow divider bellows. This causes secondary fuel port closure.

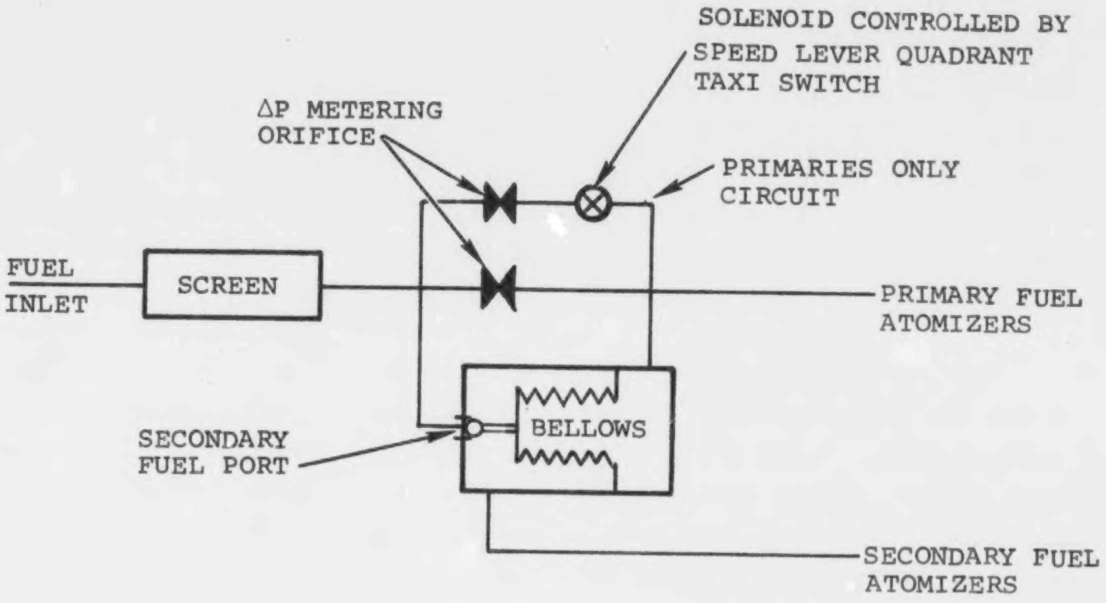
When the speed lever is advanced beyond 65 percent speed, the "primaries only" solenoid closes and the fuel control operates as a standard TPE331 control. During ignition and acceleration the speed lever will be temporarily set above 65 percent speed to allow standard mode fuel control operation. At governed speed, the speed lever is set back to 65 percent speed and the "primaries only" circuit is activated.

Load conditions 4, 5, 6, and 7 were tested with the engine operating as a standard TPE331 fuel control (primary plus secondary fuel atomizers functional).

For each of the 16 ambient test conditions, listed in Table 4-2, the following test procedure was followed:

(a) The engine was started and accelerated to governed speed, with no-load applied.

(b) A specific ambient test condition, listed in Table 4-2, was set in the test chamber and the engine was allowed to stabilize (approximately 5 minutes).


SOLENOID CONTROLLED BY
SPEED LEVER QUADRANT
TAXI SWITCH
ΔP METERING
ORIFICE
PRIMARIES ONLY
CIRCUIT
FUEL
INLET
SCREEN
PRIMARY FUEL
ATOMIZERS
BELLOWS
SECONDARY
FUEL PORT
SECONDARY FUEL
ATOMIZERS

PRIMARIES ONLY FUEL CONTROL SCHEMATIC

FIGURE 4-23

(c) The first engine load (Condition 1 in Table 4-8) was then applied to the engine and after stabilization (approximately 5 minutes), all required data was recorded. At this time the gaseous emissions, followed by particulate samples, were taken. Also, all required manual data was recorded.

(d) The above procedure was repeated for engine load Conditions 2 through 7, sequentially, with test point and emission data recorded at each condition. Completing engine load Conditions 1 through 7 constitute one test cycle at specified inlet ambient conditions.

(e) After Condition 7, the engine was returned to load Condition 1 with the inlet ambient condition remaining the same. The engine was again varied from Condition 1 to Condition 7, sequentially, and this procedure was repeated a third time. All required emission and test point data were recorded at each of the seven engine load conditions for each cycle.

To avoid confusion between data recorded by the smoke analyzer operator, gaseous emissions analyzer operator, and test cell operator, all test conditions were numbered as test points with test Point 1 being ambient inlet Condition 1, engine load Condition 1, Cycle 1, and the last test point Number 336, as ambient inlet Condition 16, engine load Condition 7, Cycle 3. The described test point numbering scheme for all conditions evaluated in this series is presented in Table 4-9.

A list of instrumentation, from which readings were recorded, is presented in Table 4-10. Further additional instrumentation for monitoring engine internal conditions, such as vibration, oil temperature and pressure, etc., were continuously observed to ensure engine integrity. These latter instrumentation readouts were not recorded. A sample of data, manually recorded during the testing is shown in Appendix II.

TABLE 4-9

TPE331 TEST POINT NUMBER MATRIX

Ambient Condition (Table 4-2)	Engine Load Data Points		
	Cycle 1	Cycle 2	Cycle 3
1	1 - Cond 1*	8 - Cond 1	15 - Cond 1
	2 - Cond 2*	9 - Cond 2	16 - Cond 2
	3 - Cond 3*	10 - Cond 3	17 - Cond 3
	4 - Cond 4*	11 - Cond 4	18 - Cond 4
	5 - Cond 5*	12 - Cond 5	19 - Cond 5
	6 - Cond 6*	13 - Cond 6	20 - Cond 6
	7 - Cond 7*	14 - Cond 7	21 - Cond 7
2	22 - 28	29 - 35	36 - 42
3	43 - 49	50 - 56	57 - 63
4	64 - 70	71 - 77	78 - 84
5	885 - 91	92 - 98	99 - 105
6	106 - 112	113 - 119	120 - 126
7	127 - 133	134 - 140	141 - 147
8	148 - 154	155 - 161	162 - 168
9	169 - 175	176 - 182	183 - 189
10	190 - 196	197 - 203	204 - 210
11	211 - 217	218 - 224	225 - 231
12	232 - 238	239 - 245	246 - 252
13	253 - 259	260 - 266	267 - 273
14	274 - 280	281 - 287	288 - 294
15	295 - 301	302 - 308	309 - 315
16	316 - 322	323 - 329	330 - 336

*Conditions 1 through 7 of Table 4-8

TABLE 4-10

TPE331-5-251M TEST INSTRUMENTATION

Parameter	Unit
Data Point	Number
Time	Sec:min:hr
Barometric Pressure	In. Hg abs
Engine Speed	Rpm
Compressor Inlet Temperature	°F
Compressor Inlet Total Pressure	In. Hg abs
Fuel Flow	Lb/hr
Corrected Fuel Flow	Lb/hr
Compressor Discharge Pressure	In. Hg abs
Compressor Discharge Temperature	°F
Exhaust Gas Temperature (avg of 8 thermocouples)	°F
Exhaust Gas Static Pressure	In. H_2O
Engine Torque	In.-lb
Turbine Interstage Temperature (avg of 16 thermocouples)	°F
Bellmouth Static ΔP	In. H_2O
Bellmouth Total Pressure	In. Hg abs
Bellmouth Inlet Temperature	°F
Engine Mass Airflow	Lb/sec
Engine Inlet Water Flow	Gph
Sample Temperature (1)	°F
" " (2)	°F
" " (3)	°F
" " (4)	°F

4.4 Data Reduction

A sample of data recorded by the test cell operator, and a strip chart recording from the gaseous emission analyses, are presented in Appendix II as typical data recorded at each test point number.

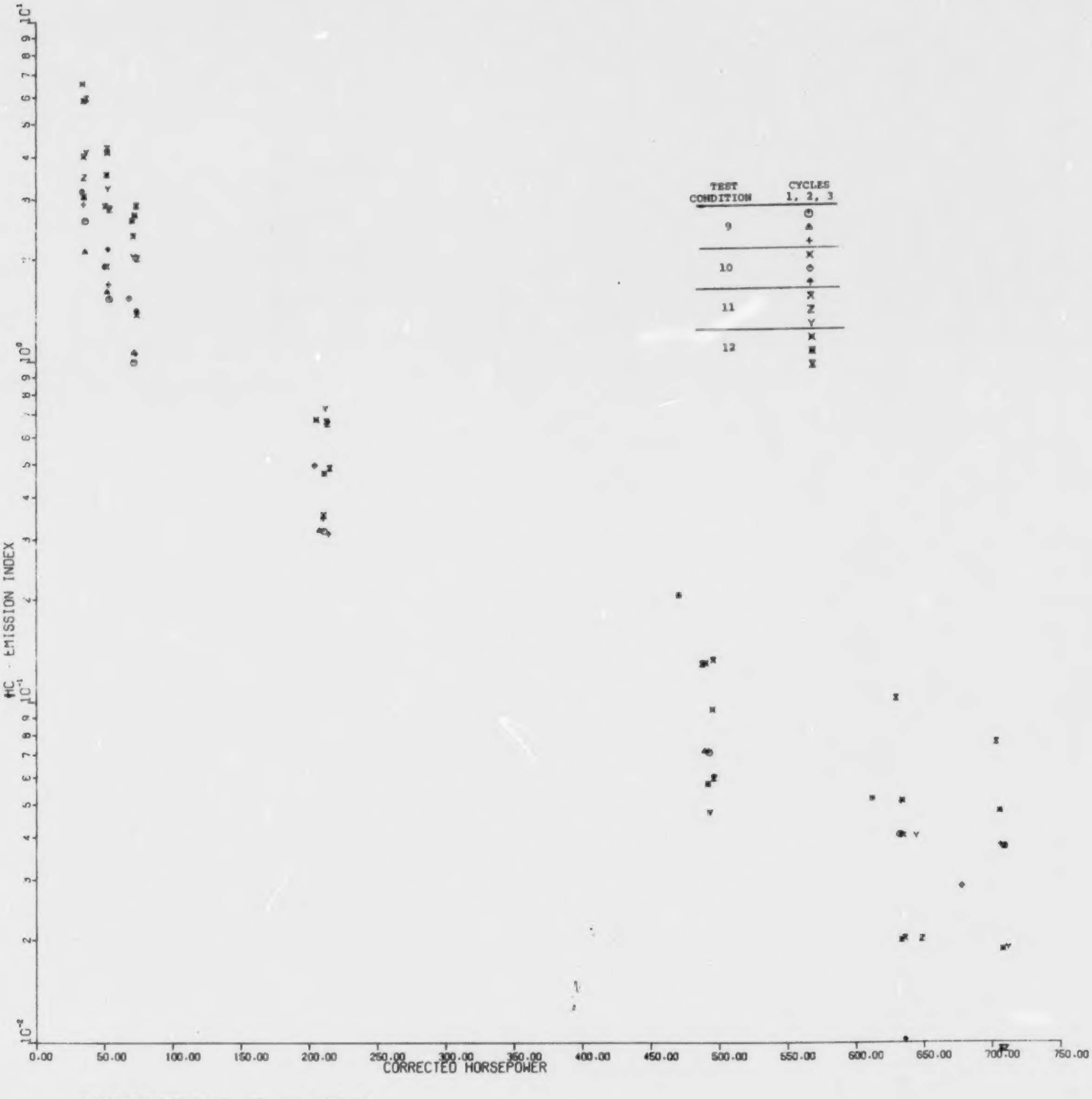
The data gathered during testing was reduced by AiResearch computer programs. Reduced computer output data for all 336 test points is presented in Volume 2 of this report. To eliminate and correct any errors produced by misreading recorded raw data, the reduced output data was plotted by the AiResearch CalComp digital plotter. Examples of this plotting procedure are presented in Figures 4-24 through 4-28 for the turboprop engine. Data plotted in this manner also permits quick visual inspection.

In determining TPE331 turboprop engine landing/takeoff cycle values, there are two optional computer subroutines, for curve fitting emissions data (Figure 4-29), replacing the originally-used least square polynominal curve fit. Curve characteristics are discussed below.

	Type of Subroutine	Comment
o	Least squares	Excessive low power range errors
o	Gauss' elimination method	Oscillation in curve fit at high power range minimized by accurately setting power points (no significant errors result).
o	Two-part curve fit	Derivatives at the "intersection" test point are not matched.

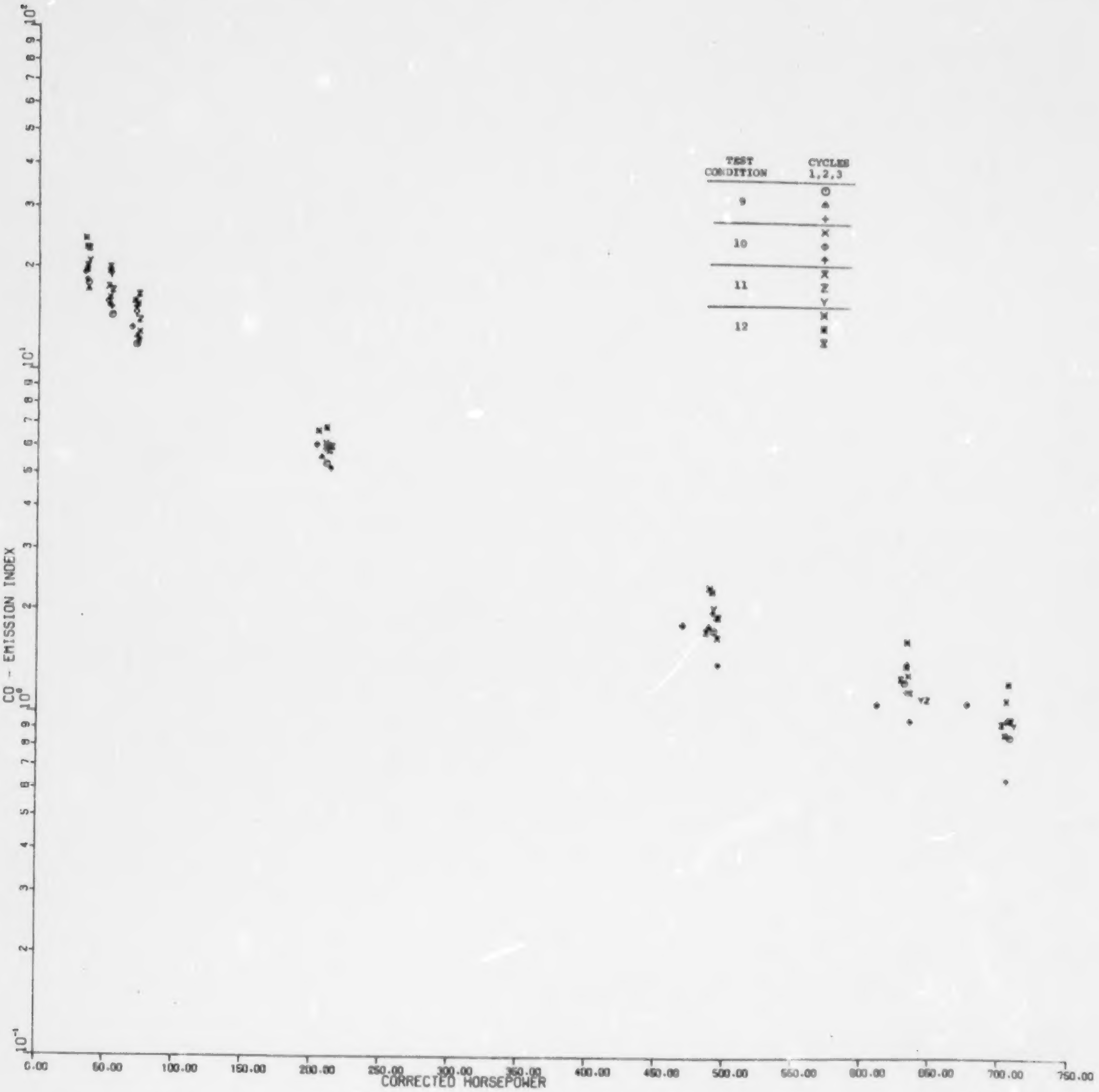
The Gauss' elimination method was utilized exclusively.

To facilitate data transmittal and processing, between AiResearch and Calspan, a computer tape data format was established.



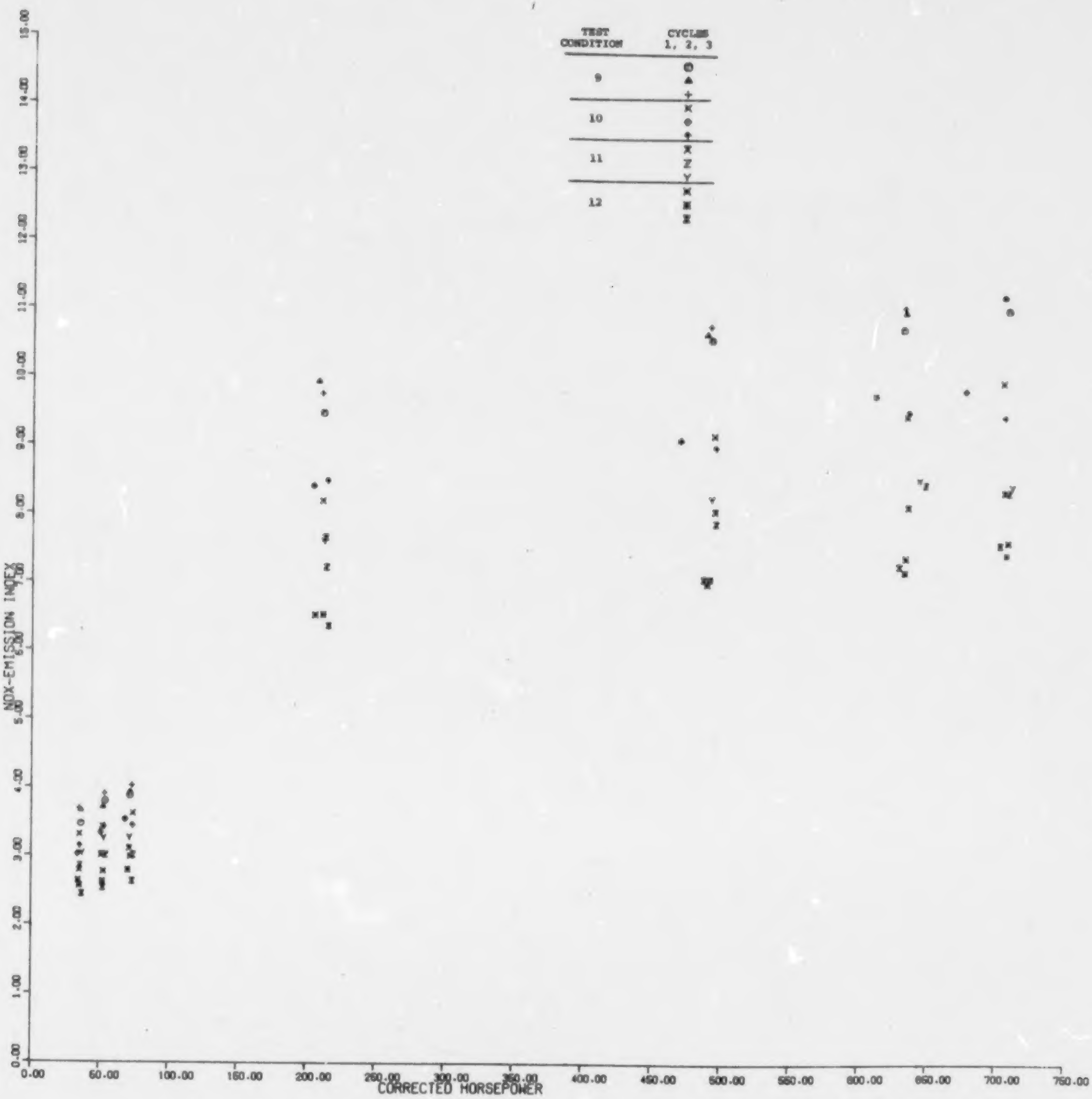
TEST CONDITIONS 9, 10, 11, AND 12

FIGURE 4-24



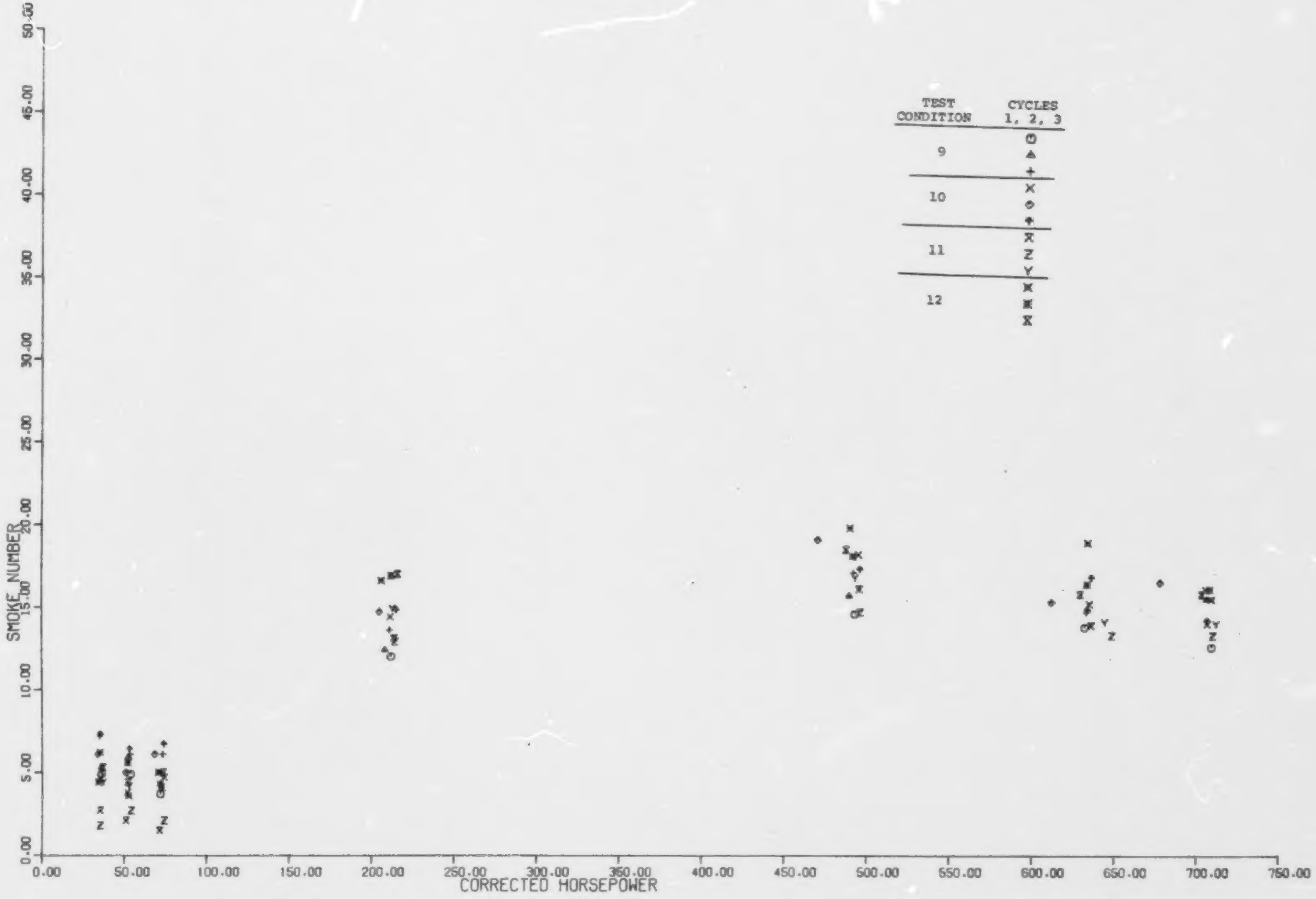
TEST CONDITIONS 9, 10, 11, AND 12

FIGURE 4-25



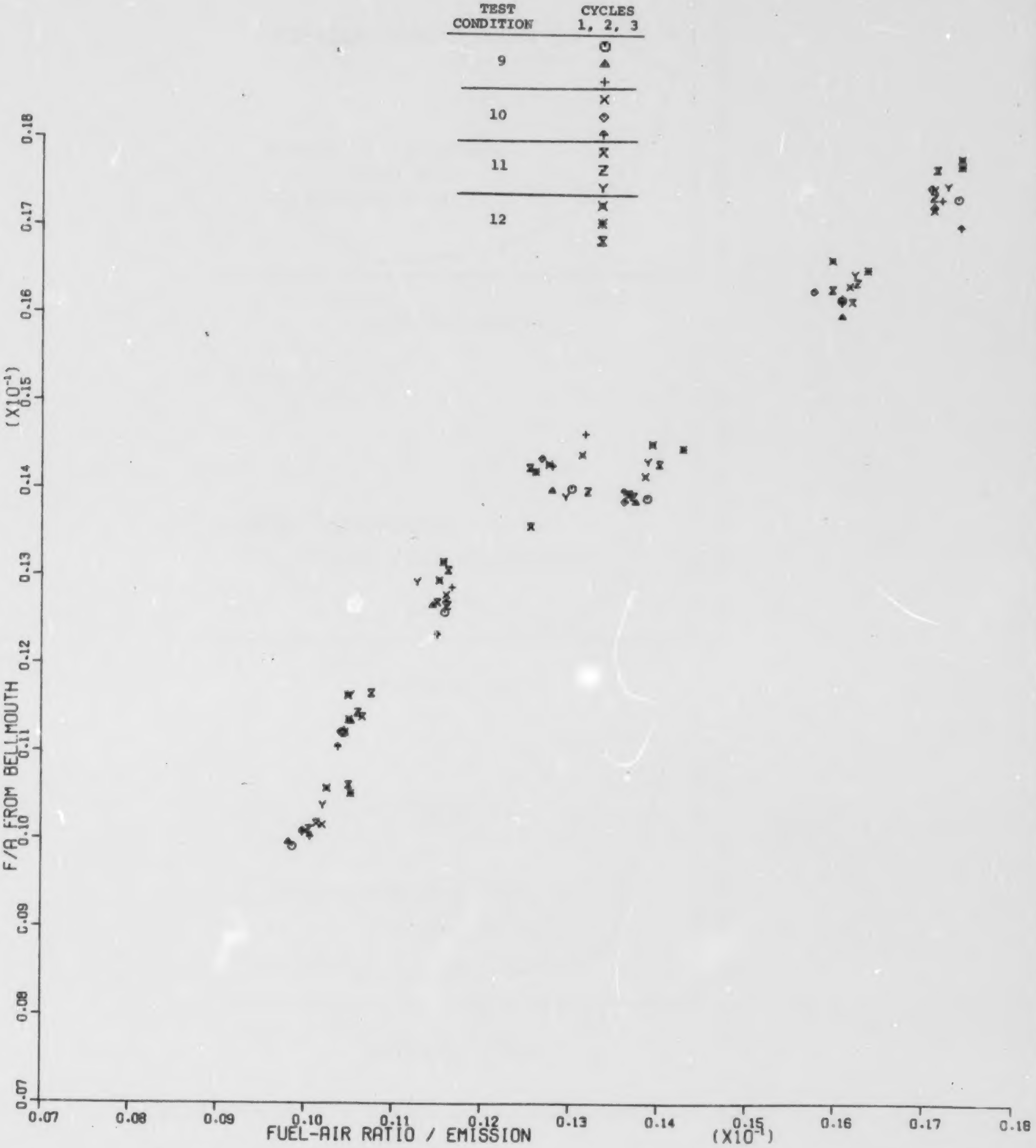
TEST CONDITIONS 9, 10, 11, AND 12

FIGURE 4-26



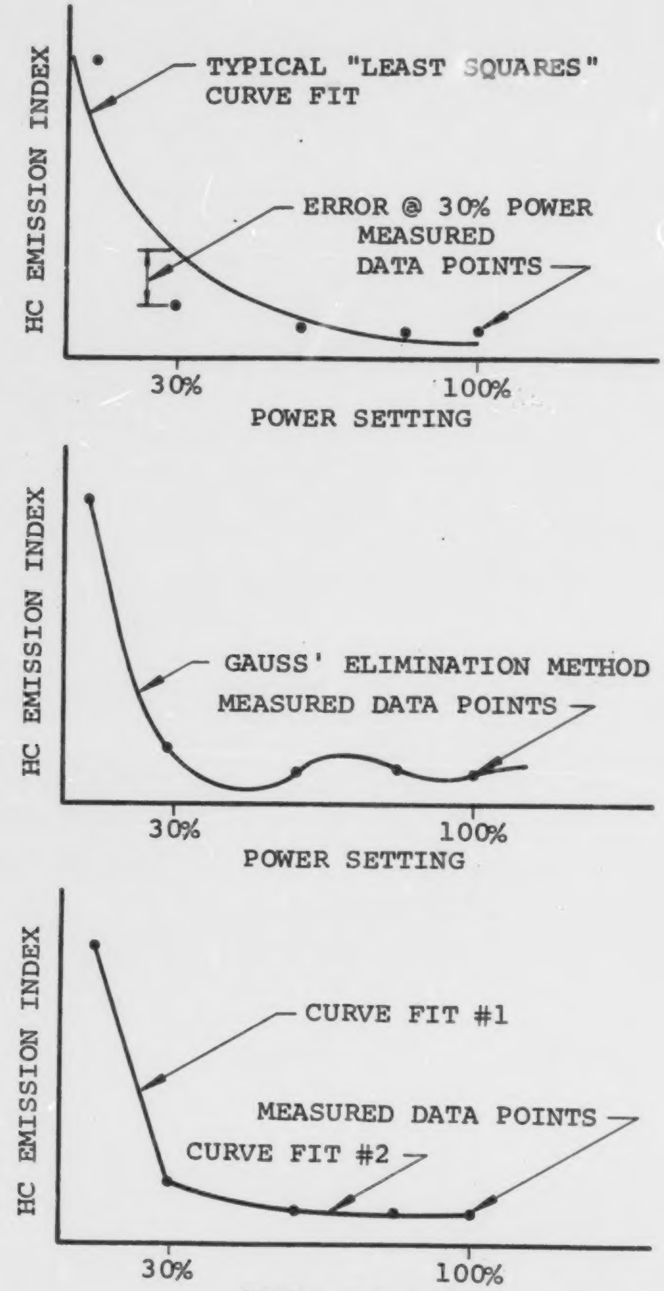
TEST CONDITIONS 9, 10, 11, AND 12

FIGURE 4-27



TEST CONDITIONS 9, 10, 11, AND 12

FIGURE 4-28



EMISSIONS DATA REDUCTION CURVE FIT SUBROUTINES

FIGURE 4-29

Data transmitted to Calspan was grouped into three general classifications:

- General identification information
- Test operational conditions
- Individual test information

Specific information included in these classifications are indicated in Tables 4-11, 4-12, and 4-13, respectively.

Sample Test Data

Prior to initiation of testing, the following items were generated for transmittal to Calspan for computer tape format and Calspan statistical analysis computer program checkout:

- Two IBM 9-track magnetic tapes containing sample emissions test data identified as tape Z043, for the GTCP85 Series APU, and tape Z044 for the TPE331 Series Engine.
- Computer listings of information on each tape
- Listings of FORTRAN programs APURT for the GTCP85 Engine and TURBPT for the TPE331 Engine which translated AiResearch CDC 6400 tape output to IBM 9-track tape.
- Output listings for the GTCP85 and TPE331 data reduction programs, from which tape output data was extracted
- A list identifying computer variables used in the above listings. For reference, this list is also presented in Table 4-14.

TABLE 4-11

GENERAL IDENTIFICATION INFORMATION FORMAT

(1) Manufacturer

(2) Engine Type and Model

(3) Serial Number

(4) Rated Shaft Horsepower (shp)

(5) Rated Speed (rpm)

(6) Engine Total Time (hr)

(7) Overhaul Information - Time Since (hrs)

    (a) Hot Section Overhaul
    (b) N_1 Compressor Overhaul
    (c) N_2 Compressor Overhaul
    (d) Combustor Can Replacement
    (e) First Stage Nozzle Guide Vane Overhaul
    (f) N_1 Turbine Overhaul
    (g) N_2 Turbine Overhaul
    (h) Overhaul Comments

(8) Fuel Type

(9) Fuel H/C Ratio

(10) Comments

TABLE 4-12

TEST OPERATIONAL CONDITIONS INFORMATION FORMAT

(1) Date

(2) Time (Zero to 2400 hrs)

(3) Sample Line Temperature, Probe Outlet (°F)

(4) Sample Line Temperature, Instrumentation Inlet (°F)

(5) Sample Line Temperature, Additional Location (°F)

(6) Sample Line Residence Time (Sec)

(7) Comments

TABLE 4-13

INDIVIDUAL TEST INFORMATION FORMAT

A. TEST IDENTIFICATION INFORMATION

(1) Engine Number

- 1 First test engine
- 2 Second test engine

(2) Replication Number

- 1 Initial test
- 2 First replication
- 3 Second replication

(3) Mode Number

- 1 Idle power
- 2 1.5 times idle power
- 3 2.0 times idle power
- 4 Climbout
- 5 Approach
- 6 Takeoff
- 7 Cruise

(4) Nominal Percent Rated Takeoff Power (e.g., 5.0, 30.0 . . . 100.0)

(5) Nominal Ambient Temperature (°F)

(6) Nominal Ambient Temperature (°F)

(7) Nominal Relative Humidity

(8) Date of Test

(9) Time of Test (Zero to 2400 hrs)

TABLE 4-13 (Contd)

B. TEST MEASUREMENT INFORMATION

(1) Measured Power Setting (hp)

(2) Measured Ambient Temperature (°F)

(3) Measured Engine Inlet Temperature (°F)

(4) Measured Barometric Pressure (in. Hg)

(5) Dew Point (°F)

(6) Measured Specific Humidity (lb H_2O/lb air)

(7) Measured Relative Humidity

(8) Measured N_1 Speed (rpm)

(9) Measured N_2 Speed (rpm)

(10) Measured Fuel Flow (lbs/hr)

(11) Measured Air Flow (lbs/sec)

(12) Measured Bleed Air Flow (lbs/sec) (APU only)

(13) Measured Bleed Air Pressure (psia) (APU only)

(14) P_{t_7} - Standard Gas Turbine Parameter

(15) T_{t_7} - Standard Gas Turbine Parameter

(16) HC - Concentration of Hydrocarbons in ppm Carbon Equivalent (equivalent propane X3) Wet

(17) CO - Concentration of Carbon Monoxide in ppm by Volume, Wet

(18) CO_2 - Concentration of CO_2 in Volume Percent, Wet

(19) NO_x - Concentration of Oxides of Nitrogen in ppm by Volume ($NO + NO_2$), Wet

TABLE 4-13 (Contd)

(21) NO - concentration of NO in ppm by volume (weight as NO_2), wet

(22) NO_2 - concentration of NO_2 in ppm by volume, wet

(23) Smoke Number = SN (Interpolated from SN-vs - W/A graph where W/A = 0.0230 lb/sq in)

(24) W/A Sample No. 1 (lb/sq in)

(25) SN Sample No. 1

(26) W/A Sample No. 2 (lb/sq in)

(27) SN Sample No. 2

(28) W/A Sample No. 2 (lb/sq in)

(29) SN Sample No. 3

(30) W/A Sample No. 4 (lb/sq in)

(31) SN Sample No. 4

(32) Comments

C. CALCULATED MODEL TEST INFORMATION

(1) HC Emission Rate (lbs/hr)

(2) CO Emission Rate (lbs/hr)

(3) NO_x Emission Rate (lbs/hr)

(4) Fuel Flow (lbs/hr)

(5) HC Emission Index (lbs/1000 lb fuel)

(6) CO Emission Index (lbs/1000 lb fuel)

(7) NO_x Emission Index (lbs/1000 lb fuel)

TABLE 4-14

VARIABLE IDENTIFICATION

NTEST	Number of Test Conditions
NDATE	Date of Test
TIME	Time of Test Run
PBARO	Phoenix Barometric Pressure, in. of Hg
TAMB	Phoenix Ambient Air Temperature, Deg F
RELHUM	Phoenix Ambient Relative Humidity, percent
CALID	Calculation Number
TESTNO	Test Number
KTEST	Test Point Number
TCIFO	Compressor Inlet Temperature, Deg F
HPMEAS	Measured Horsepower
HPCORR	Corrected Horsepower (to standard day conditions)
SHPRAT	Percent Rated Horsepower
EGT	Exhaust Gas Temperature, Deg F
WFCO	Measured Fuel Flow, lbm/hr
FAD	Fuel/Air Ratio Calc from Emissions
FHI	Equivalence Ratio
XN10	Compressor Spool Speed, rpm
PCDO	Compressor Discharge Air Pressure, psia
TCDF	Compressor Discharge Air Temperature, Deg F
TITF	Turbine Inlet Temperature, Deg F
WBLED	Compressor Bleed Airflow (Meas), lb/sec
PBLE	Bleed Air Pressure, psia
TBLEDF	Bleed Air Temperature, Deg F
WMAP	Compressor Map Airflow, lb/sec
FAMAP	Fuel/Air Ratio Based on Map Airflow
ELP	Combustor Loading Parameter
ETA	Combustor Efficiency (from Emissions)
EGP	Exhaust Gas Pressure, Static, psia
CO2W	Carbon Dioxide Wet Emission Concentration, Percent by Volume
ECO$_2$	Carbon Dioxide Emission Rate, lb/hr
GCO2	Carbon Dioxide Emission Index, lb/(1000 lb of fuel)
COW	Carbon Monoxide Wet Emission Concentration, PPMV
ECO	Carbon Monoxide Emission Rate, lb/hr
GCO	Carbon Monoxide Emission Index, lb/(1000 lb of fuel)
HCHW	Hydrocarbon Wet Emission Concentration (HC as CH4) PPMC
EHCH	Hydrocarbon Emission Rate, lb/hr
GHCH	Hydrocarbon Emission Index, lb/(1000 lb of fuel)
NOW	Nitric Oxide Wet Emission Concentration (Weighted as NO$_2$), PPMV
ENO	Nitric Oxide Emission Rate, lb/hr
GNO	Nitric Oxide Emission Index, lb/(1000 lb of fuel)
NO$_2$W	Nitrogen Dioxide Wet Emission Concentration, PPMV
ENO$_2$	Nitrogen Dioxide Emission Rate, lb/hr
GNO2	Nitrogen Dioxide Emission Index, lb/(1000 lb of fuel)
NOXW	Total Oxides of Nitrogen Wet Emission Concentration, (NO + NO$_2$) as NO$_2$, PPMV

TABLE 4-14 (Contd)

ENOX	Total Oxides of Nitrogen Emission Rate, lb/hr
GNOX	Total Oxides of Nitrogen Emission Index, lb/(1000 lb of fuel)
SNT	Smoke Number at W/A = 0.0230 lb/sq in.
WASN1	W/A Sample No. 1, lb/sq in.
SN1	Smoke Number Sample No. 1
WASN2	W/A Sample No. 2, lb/sq in.
SN2	Smoke Number Sample No. 2
WASN3	W/A Sample No. 3, lb/sq in.
SN3	Smoke Number Sample No. 3
WASN4	W/A Sample No. 4, lb/sq in.
SN4	Smoke Number Sample No. 4
DUMMY	Five empty files for additional data
WBELL	Measured Bellmouth Flow, lbm/sec
FABELL	Fuel/Air Ratio Based on Bellmouth Flow
EGPS	Exhaust Gas Pressure, Static, psig
TSECH	Total Hydrocarbon Cycle Emissions, lb/1000 lb-horsepower-hr per cycle
TSECO	Total Carbon Monoxide Cycle Emission, lb/1000 lb-horsepower-hr per cycle
TSENOX	Total Oxides of Nitrogen Cycle Emissions, lb/1000 lb-horsepower-hr per cycle

4.5 Emissions Sampling Probe

A tabulation of the measured fuel air ratio, calculated fuel air ratio from gaseous exhaust emissions, and percentage difference for 28 Model TPE331 Turboprop Engines is presented in Table 4-15. All engines were sampled with a probe of identical construction to Drawing SKP32566 (enclosed in Appendix III) to verify design intent for this program. The measured fuel air ratio was determined from engine airflow data obtained with an inlet bellmounth and engine fuel flow data obtained with a turbine flowmeter. The calculated fuel-air ratio was determined from gaseous exhaust emissions by a carbon balance.

Comparing the measured fuel air ratio with the calculated fuel air ratio shows that 143 of the 150 points have a percentage difference less than 8.0 percent. A closer examination indicated that three occurred on one engine. Three other test points were at the lowest fuel air ratio tested, where small errors in measurement result in large percentage differences.

The average percentage difference for each test condition for all 28 engines, also presented in Table 4-15, varied between 4.1 and 5.1 percent. The average percentage difference for all 140 points was determined to be 4.5 percent. Considering the effect of measuring equipment errors, the gaseous exhaust emission samples gathered are representative of the exhaust gas. Therefore, this probe is considered satisfactory.

TEST CONDITION ▷ POWER SETTING ▷		1 100 PERCENT			2 90 PERCENT			3 70 PERCENT			4 50 PERCENT			5 30 PERCENT		
Engine Model	Serial Number	F/A meas	F/A emis	% dif	F/A meas	F/A emis	% dif	F/A meas	F/A emis	% dif	F/A meas	F/A emis	% dif	F/A meas	F/A em.	% dif
T76-G-417	P-00899	.0186	.0188	1.1	.0170	.0173	1.7	.0149	.0152	2.0	.0119	.0124	4.1	.0098	.0099	1.0
	CE-00897	.0182	.0196	7.1	.0169	.0181	6.6	.0149	.0155	3.9	.0120	.0124	3.2	.0098	.0099	1.0
TPE331-5-251	P06165	.0157	.0165	4.8	.0145	.0152	4.6	.0129	.0133	3.0	.0105	.0111	5.4	.0087	.0094	7.4
	P06160	.0156	.0163	4.3	.0143	.0150	4.7	.0127	.0134	5.2	.0103	.0108	4.6	.0087	.0093	7.8
	P06181	.0165	.0166	0.6	.0146	.0151	3.3	.0129	.0134	3.7	.0106	.0110	3.6	.0088	.0094	6.4
	P06185	.0154	.0164	6.1	.0143	.0151	5.3	.0126	.0133	5.3	.0102	.0110	7.3	.0085	.0094	9.6
	P06191	.0158	.0162	2.5	.0145	.0151	4.0	.0129	.0133	3.0	.0104	.0109	4.6	.0087	.0091	4.4
TPE331-6-251	P20172	.0157	.0167	6.0	.0146	.0154	5.2	.0127	.0134	5.2	.0104	.0107	2.8	.0087	.0092	5.4
	P20167	.0158	.0167	5.4	.0146	.0153	4.6	.0130	.0134	3.0	.0104	.0112	7.1	.0088	.0094	6.4
	P20188	.0160	.0168	4.8	.0146	.0153	4.6	.0130	.0136	4.4	.0105	.0111	5.4	.0087	.0094	7.4
	P20190	.0159	.0168	5.4	.0148	.0155	4.5	.0131	.0138	5.1	.0105	.0112	6.3	[illegible]	[illegible]	7.4
	P20198	.0157	.0167	6.0	.0145	.0154	5.8	.0129	.0136	5.1	.0105	.0109	3.7	.0087	.0093	6.5
	P20201	.0156	.0167	6.6	.0145	.0152	4.6	.0129	.0135	4.4	.0105	.0110	4.5	.0089	.0094	5.3
TPE 331-2-201	P90066	.0187	.0213	11.3	.0174	.0190	8.4	.0150	.0164	8.5	.0122	.0122	0.0	.0099	.0101	2.0
	P90032	.0188	.0198	5.1	.0171	.0173	1.2	.0149	.0152	2.0	.0119	.0121	1.7	.0098	.0101	3.0
	P92056	.0178	.0194	8.2	.0161	.0174	7.5	.0142	.0150	5.3	.0112	.0119	5.9	.0092	.0096	4.2
	P90094	.0178	.0195	8.6	.0163	.0175	6.9	.0142	.0147	3.4	.0114	.0118	3.4	.0093	.0095	2.1
TPE331-3U-3G	P03015	.0169	.0181	7.2	.0163	.0169	3.6	.0143	.0140	-2.1	.0114	.0109	-4.6	.0092	.0095	3.2
	P03106	.0171	.0175	2.3	.0164	.0168	2.4	.0144	.0147	2.0	.0114	.0115	0.9	.0093	.0095	2.1
	P03047	.0173	.0185	6.5	.0169	.0181	6.6	.0147	.0158	7.0	.0116	.0124	6.5	.0094	.0100	6.0
	Repl. P03047	.0185	.0194	4.6	.0176	.0184	4.3	.0153	.0162	5.6	.0120	.0125	4.0	.0096	.0101	5.0
TPE331-3U-303G	P03097	.0174	.0180	3.3	.0163	.0170	4.1	.0113	.0120	5.8	.0092	.0098	6.1	.0076	.0082	7.3
	P03005	.0172	.0184	6.5	.0166	.0173	4.0	.0144	.0154	6.5	.0115	.0119	3.4	.0090	.0098	8.2
	P03107	.0168	.0167	-0.6	.0149	.0159	6.3	.0145	.0144	-0.6	.0111	.0113	1.8	.0089	.0095	6.3
TPE331-3UW-3	P05031	.0163	.0170	4.1	.0142	.0144	1.4	.0113	.0118	4.2	.0091	.0096	5.2	.0124	.0120	-3.3
TPE331-1-151	P92097	.0187	.0184	-1.6	.0163	.0168	3.0	.0143	.0146	2.1	.0116	.0117	0.9	.0096	.0096	0.0
	P92056	.0173	.0180	3.9	.0160	.0164	2.4	.0142	.0148	4.1	.0114	.0119	4.2	.0093	.0099	6.1
	P92249	.0175	.0189	7.4	.0162	.0171	5.3	.0142	.0146	2.7	.0114	.0117	2.6	.0094	.0096	2.1
Average Percentage Difference				5.1			4.5			4.1			4.1			5.0

COMPARISON OF MEASUREMENT AND CALCULATED FUEL/AIR RATIO

TABLE 4-15

4.6 Sampling Transport Time

Sample transport time was mathematically determined by calculating the sample tube volume from the probe to the analyzing equipment and dividing by the volumetric sample flow rate. The calculations are for dimensions given in Figure 4-30.

$$V_T = (\pi d^2/4)L$$

where,

V_T = Volume of tubing
d = Inside diameter of tubing
L = Tubing length

$$V_T = \left(\pi(0.188)^2/4\right) \text{ x } 25 \text{ x } 12 + \quad (0.436)^2/4 \quad \text{ x } 30 \text{ x } 12$$

$$V_T = 62.076 \text{ in.}^3 = 0.036 \text{ ft}^3$$

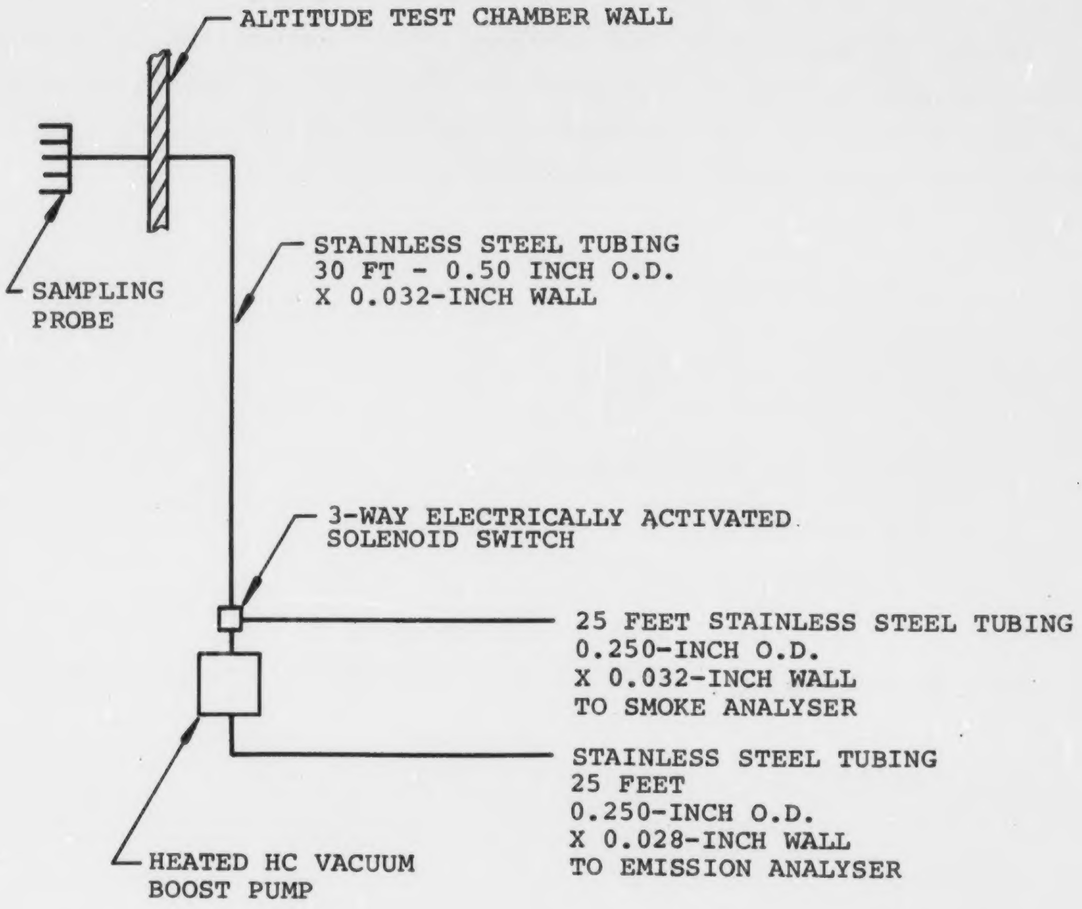
$$T = V_T/Q$$

where,

T = Transport time
Q = Sample flow rate (20 ft^3/hr std)

$$T = 0.036/20/3600$$

$$T = 6.5 \text{ seconds}$$


ALTITUDE TEST CHAMBER WALL
SAMPLING PROBE
STAINLESS STEEL TUBING 30 FT - 0.50 INCH O.D. X 0.032-INCH WALL
3-WAY ELECTRICALLY ACTIVATED SOLENOID SWITCH
25 FEET STAINLESS STEEL TUBING 0.250-INCH O.D. X 0.032-INCH WALL TO SMOKE ANALYSER
STAINLESS STEEL TUBING 25 FEET 0.250-INCH O.D. X 0.028-INCH WALL TO EMISSION ANALYSER
HEATED HC VACUUM BOOST PUMP

HEATED HC VACUUM BOOSTER PUMP

FIGURE 4-30

5.0 DISCUSSION AND ANALYSIS OF TEST RESULTS

5.1 GTCP85-98CK APU

Bleed-air APUs operate over a wide range of combustion system airflows even though APUs are classified as constant speed machines. The engine is loaded by increasing bleed-air flow and/or applying shaft power loads. When applying shaft power only, the total engine airflow passes through the combustor. Therefore, a maximum shaft-load only point represents maximum combustor throughflow, while a maximum bleed-air extraction point represents minimum combustor throughflow. A combined shaft and bleed-air load is the APU normal operating mode. Appropriate test power settings were selected to encompass the total range of combustion system throughflow anticipated in normal service.

For an APU there is a distinction between the engine maximum load rating and maximum load that can be applied to the engine as installed in the aircraft. Quite often an APU has a maximum rated power capability greater than the customer can utilize. In these cases, maximum rated power becomes a function of the installation rather than the engine. The effect of an installed engine test is generally an increase in carbon monoxide and hydrocarbon emissions and a decrease in NO_x emissions, when compared with engine emission levels at true maximum thermodynamic power capability.

As a result, it was difficult to maintain a constant corrected total power output for engine load Conditions 4 and 5 of Table 4-1, over the range of ambient test conditions, because compressor discharge temperature decreases with increasing simulated humidity. Since APU total power output is a combination of shaft and bleed-air extraction loads, the depressed compressor discharge temperature resulting from increasing humidity, decreases the bleed-air equivalent power. Where the bleed-air equivalent power contribution, to the total power output, may be expressed as follows:

Bleed-air equivalent power = $W_a c_p (T_2 - T_1) \times 1.416$, hp

where,

c_p = air specific heat at compressor discharge

W_a = mass airflow at the bleed-air exit port

T_2 = compressor discharge total temperature

T_1 = compressor inlet total temperature

The bleed-air exit port mass flow, and air specific heat, are only slightly affected by changes in pressure and temperature at the engine inlet. However, compressor discharge temperature is reduced by increasing simulated humidity, resulting in decreased bleed-air equivalent power. This means that to maintain a constant corrected total power with increasing simulated humidity, the bleed-air mass flow discharged through the bleed-air exit port must be increased. Thus, the requirement of maintaining a constant corrected total power over the range of engine ambient test conditions, required numerous engine adjustments and onsite calculations to determine if the required engine power setting was achieved. As a result, some variations in total engine power was unavoidably observed for load Conditions 4 and 5 over the range of engine ambient test conditions.

Additionally, the following considerations existed:

(a) Specific heat of air entering the combustor is increased by adding water. Specific heat of a high humidity mixture can be increased by as much as five percent.

(b) Compressor efficiency usually increases with high humidity mixtures. However, this benefit is offset by a reduction in engine total mass flow caused by the combined effects of reducing engine corrected speed and increasing air mixture physical properties.

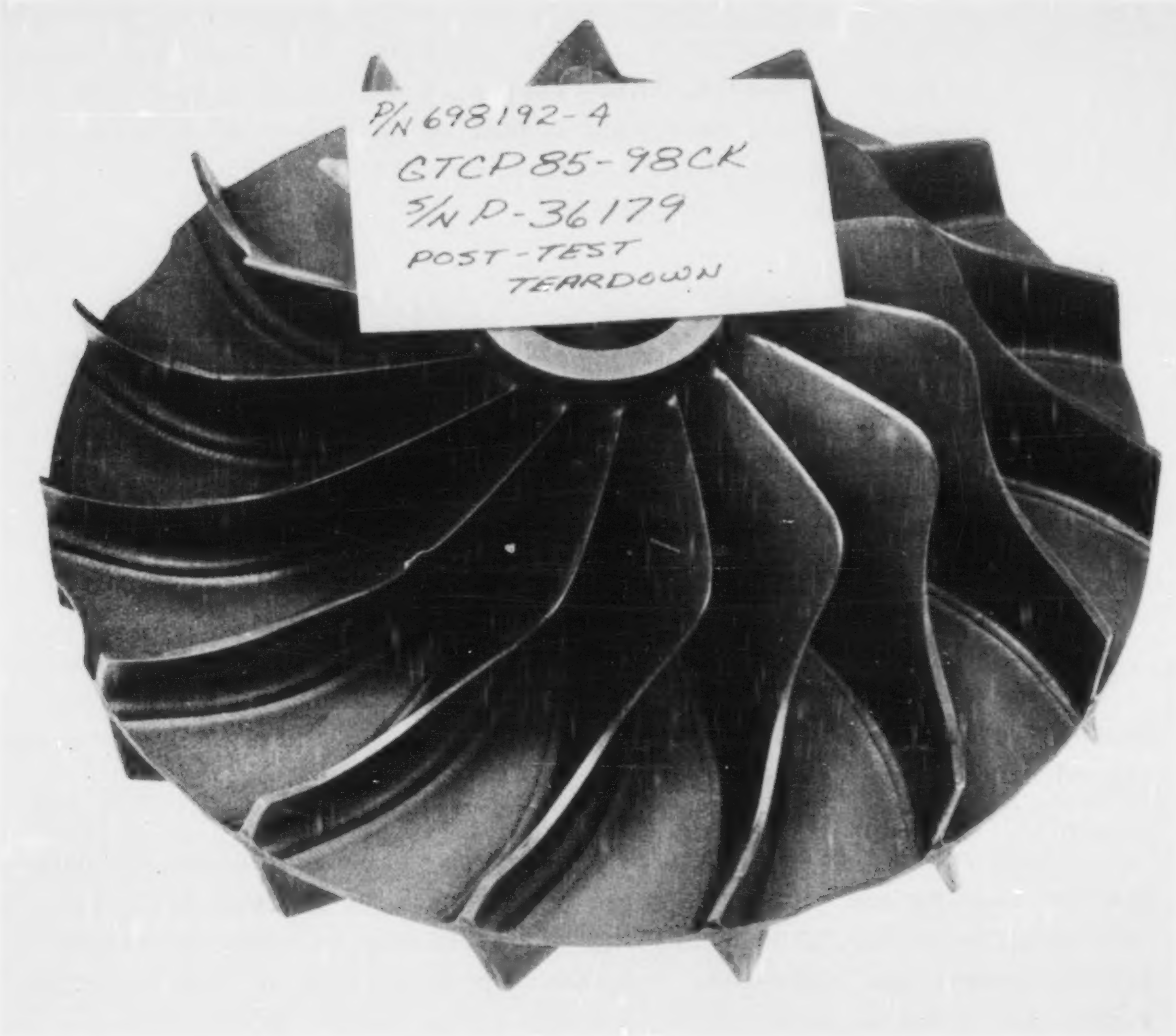
(c) Compressor depressed discharge temperatures resulting from the humidity simulation technique used, which more nearly approximate water injection in droplet form, are decreased further than that resulting from a true ambient humidity mixture. Since bleed-air equivalent power is dependent on bleed-port exit flow physical properties, including temperature, the engine must be operated at a higher power level to produce the same corrected total horsepower.

After completing eighty-two hours of engine test operation, the GTCP85-98CK APU was removed from the test cell and disassembled according to teardown inspection procedures.

Teardown inspection revealed minor foreign object damage to compressor section components as shown by Figures 5-1 through 5-5. An illustration of the GTCP85 rotating group stackup is shown in Figure 5-6 (to relate the compressor components photographed to corresponding locations in the engine).

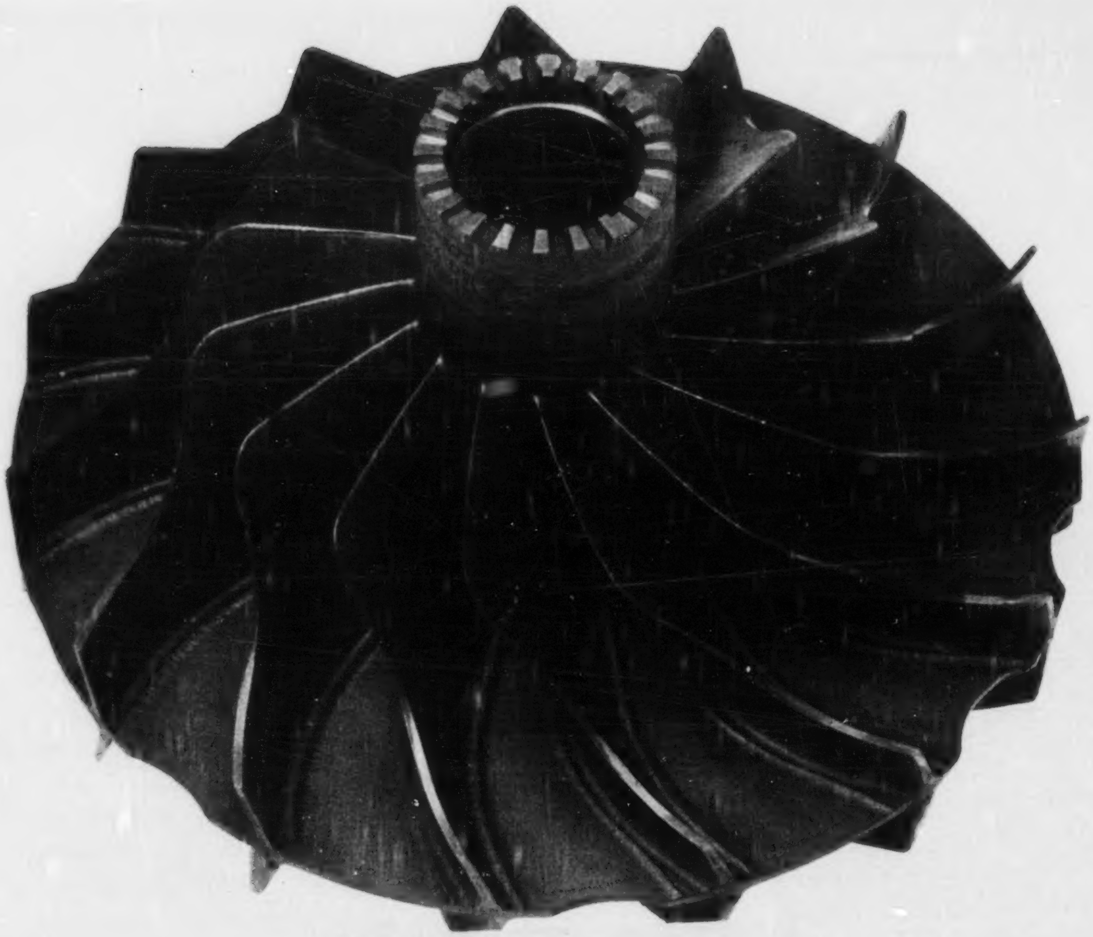
Figures 5-1 and 5-2 indicate that the first-stage compressor received slight foreign object damage. Figures 5-3 and 5-4 show the second-stage compressor and housing damaged areas. Apparently, the object was trapped between the compressor housing and second-stage compressor leading edge where it remained until pulverized.

The exit diffuser shown in Figure 5-5 indicates that no further engine damage occurred downstream. It was concluded that foreign


P/N 698192-4
GTCP85-98CK
S/N P-36179
POST-TEST
TEARDOWN

FRONT VIEW OF DUAL ENTRY
RADIAL FLOW FIRST STAGE COMPRESSOR

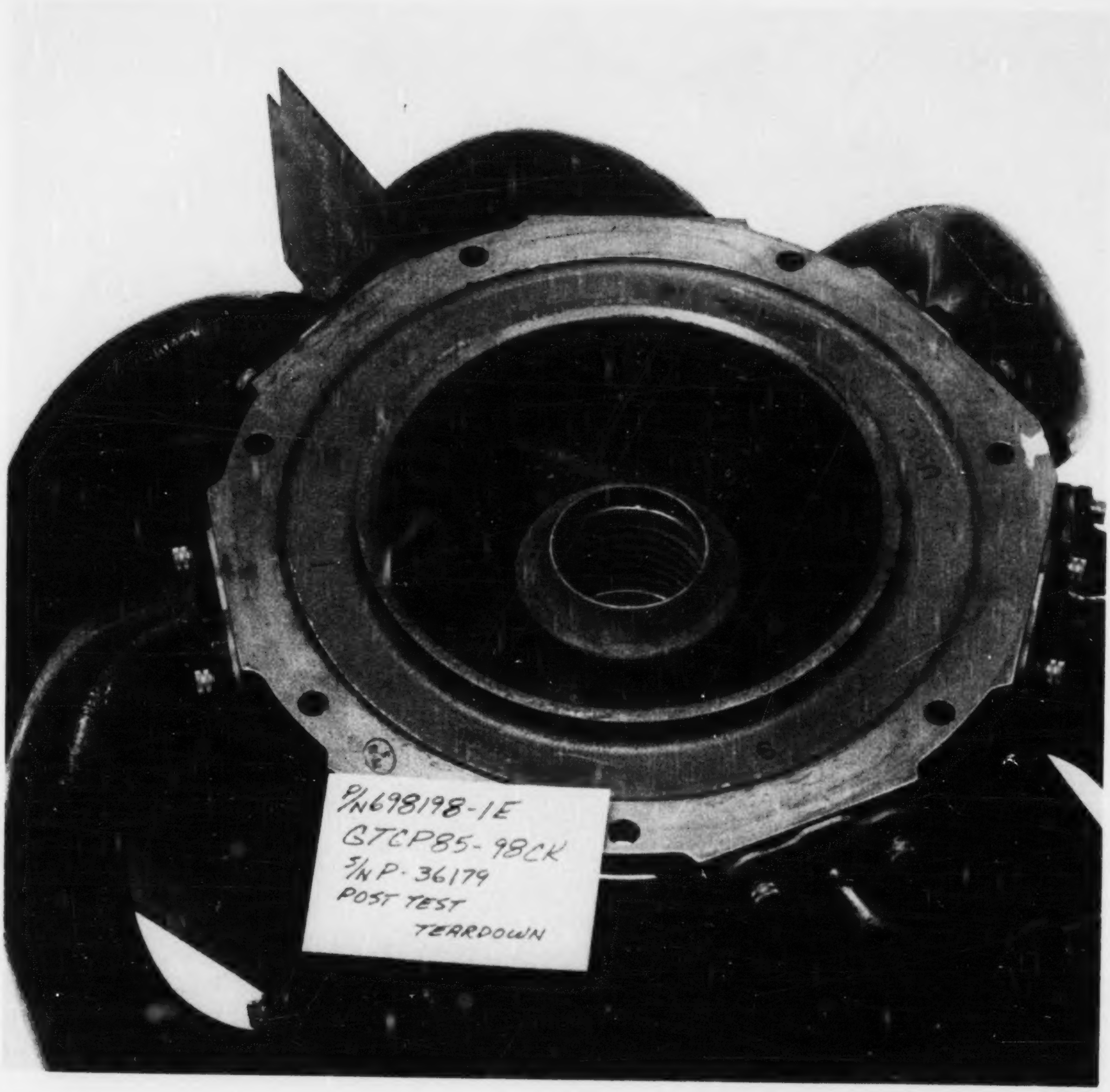
FIGURE 5-1



P/N 698192-4
GTCP85-98CK
S/N P-36179
POST-TEST
TEARDOWN

BACK VIEW OF DUAL ENTRY
RADIAL FLOW FIRST STAGE COMPRESSOR

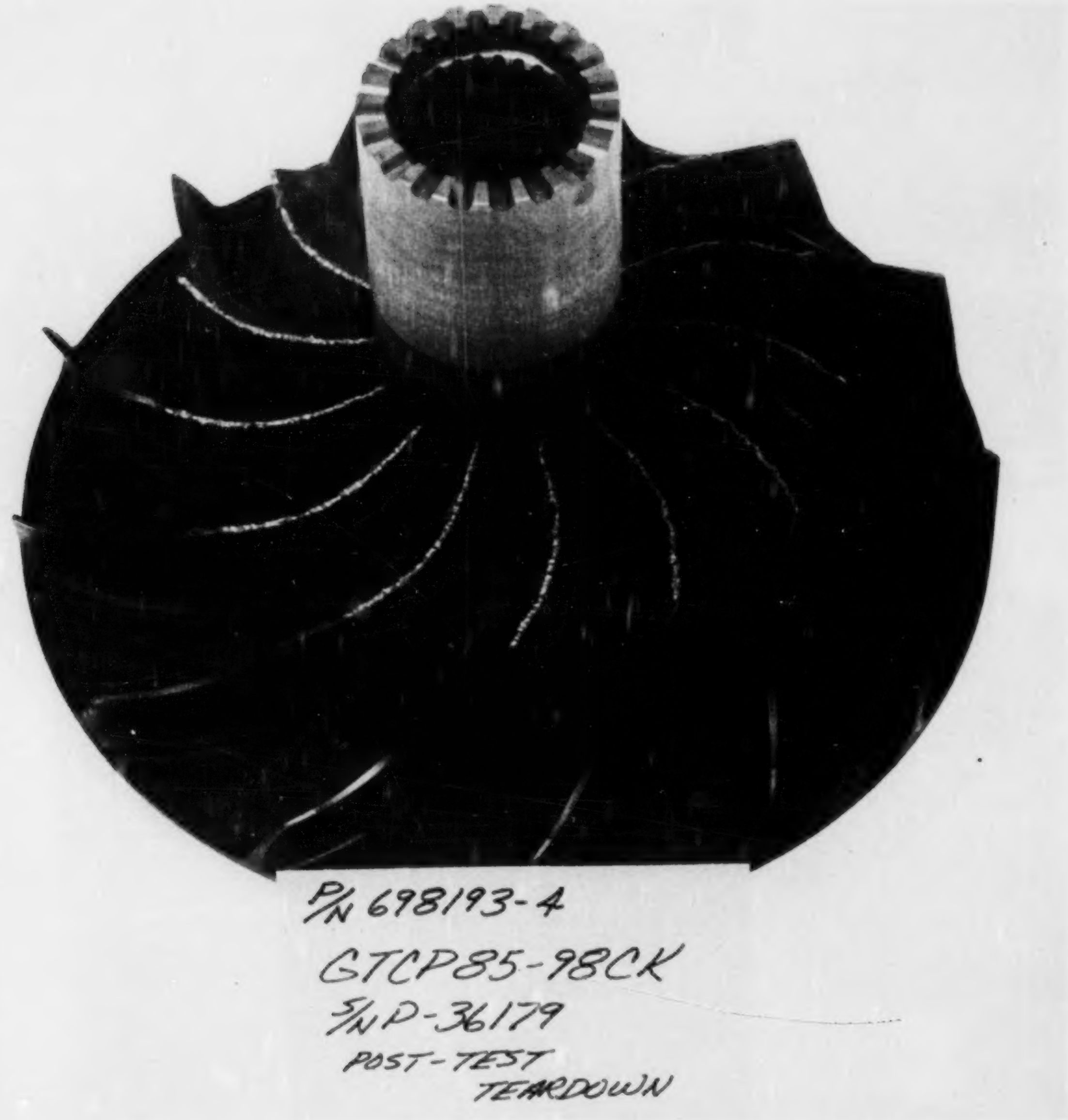
FIGURE 5-2


P/N 698198-1E
GTCP85-98CK
S/N P-36179
POST TEST
TEARDOWN

BACK VIEW OF INTERMEDIATE
HOUSING ASSEMBLY

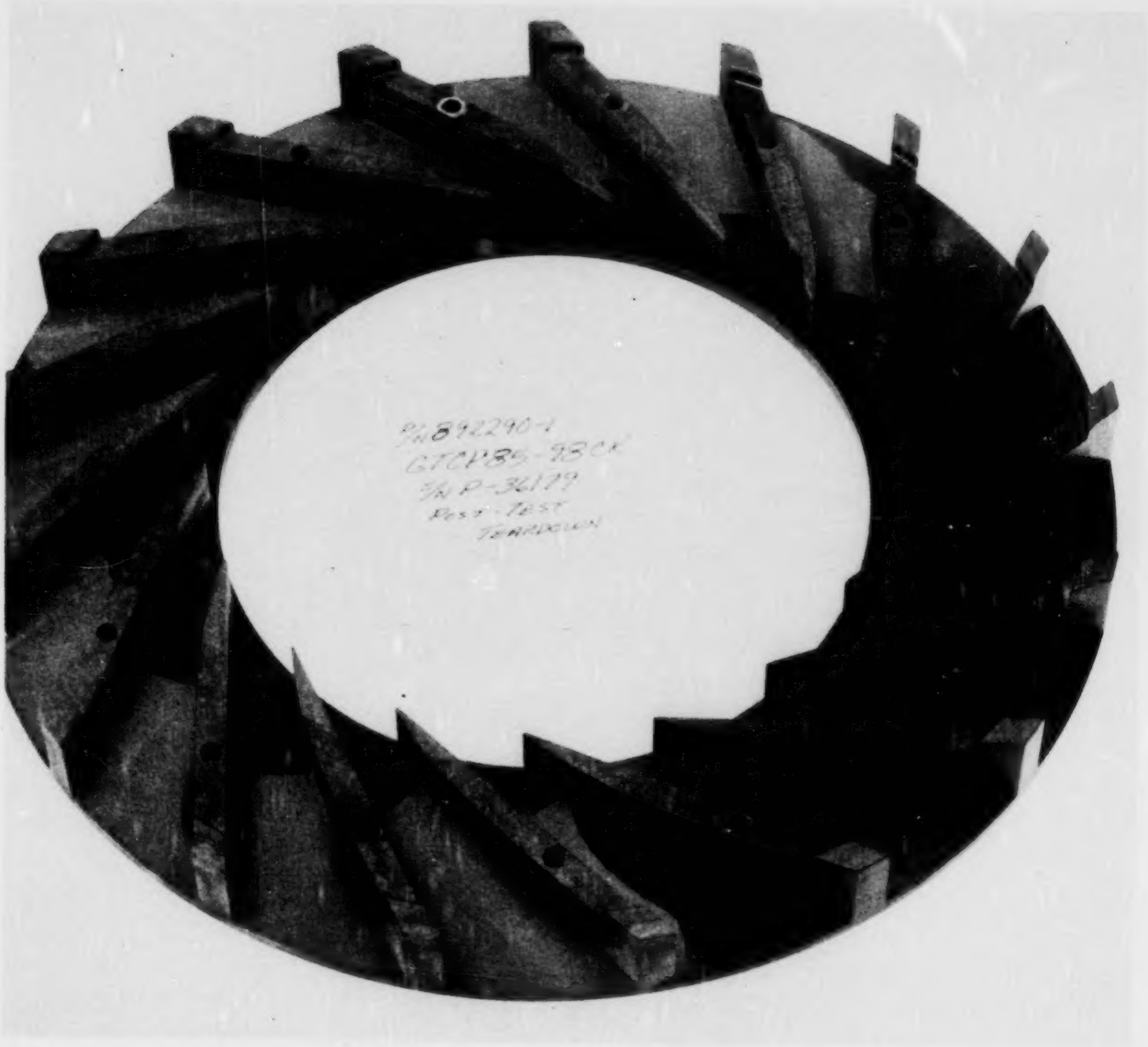
FIGURE 5-3

MP-50414


P/N 698193-4
GTCP85-98CK
S/N P-36179
POST-TEST
TEARDOWN

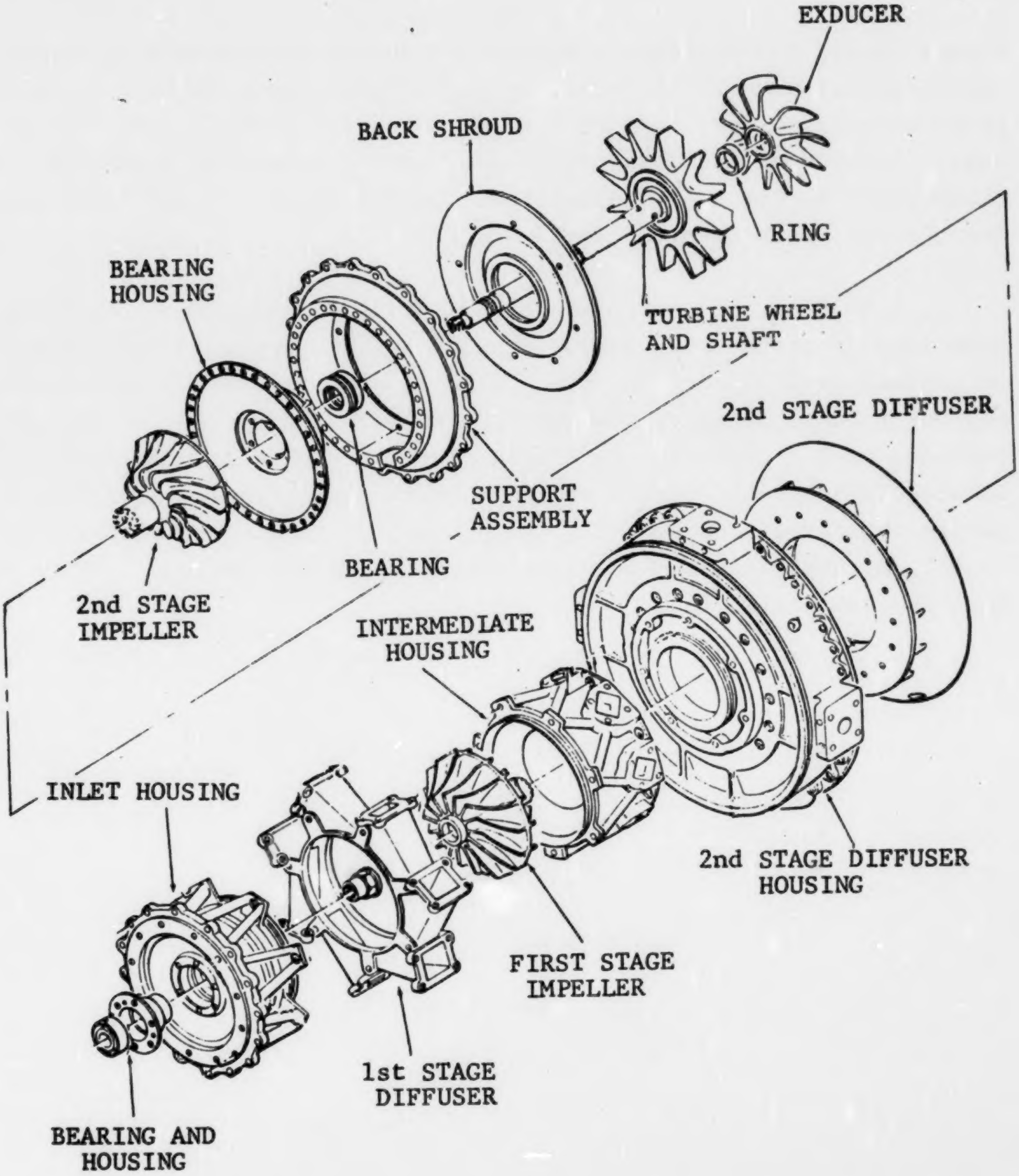
FRONT VIEW OF RADIAL FLOW
SECOND STAGE COMPRESSOR

FIGURE 5-4


P/N 892290-1
GTCP85-98CK
S/N P-36179
POST-TEST
TEARDOWN

FRONT VIEW OF SECOND
STAGE DIFFUSER ASSEMBLY

FIGURE 5-5


EXDUCER
BACK SHROUD
RING
BEARING HOUSING
TURBINE WHEEL AND SHAFT
2nd STAGE DIFFUSER
SUPPORT ASSEMBLY
BEARING
2nd STAGE IMPELLER
INTERMEDIATE HOUSING
INLET HOUSING
2nd STAGE DIFFUSER HOUSING
FIRST STAGE IMPELLER
1st STAGE DIFFUSER
BEARING AND HOUSING

GTCP85 ROTATING GROUP

FIGURE 5-6

object damage had negligible effects on engine performance by comparing engine performance characteristics during acceptance testing, with a post-calibration test conducted prior to engine removal from the test cell. Acceptance and post-calibration test results are presented in Table 5-1. A plot of corrected fuel flow-versus-corrected total power for the two tests is shown in Figure 5-7.

A 3 to 5 percent performance reduction was determined. Note that some loss in performance can be expected with operating time. Also, to satisfy test objectives, the post-calibration test was conducted at a lower turbine discharge temperature than that specified by the acceptance test procedure. As a result, the performance comparison indicates that actual loss in engine performance due to foreign object damage was small, and within 1 to 2 percent. In all probability, the object was ingested during engine check-out in the test cell prior to test program initiation.

TABLE 5-1

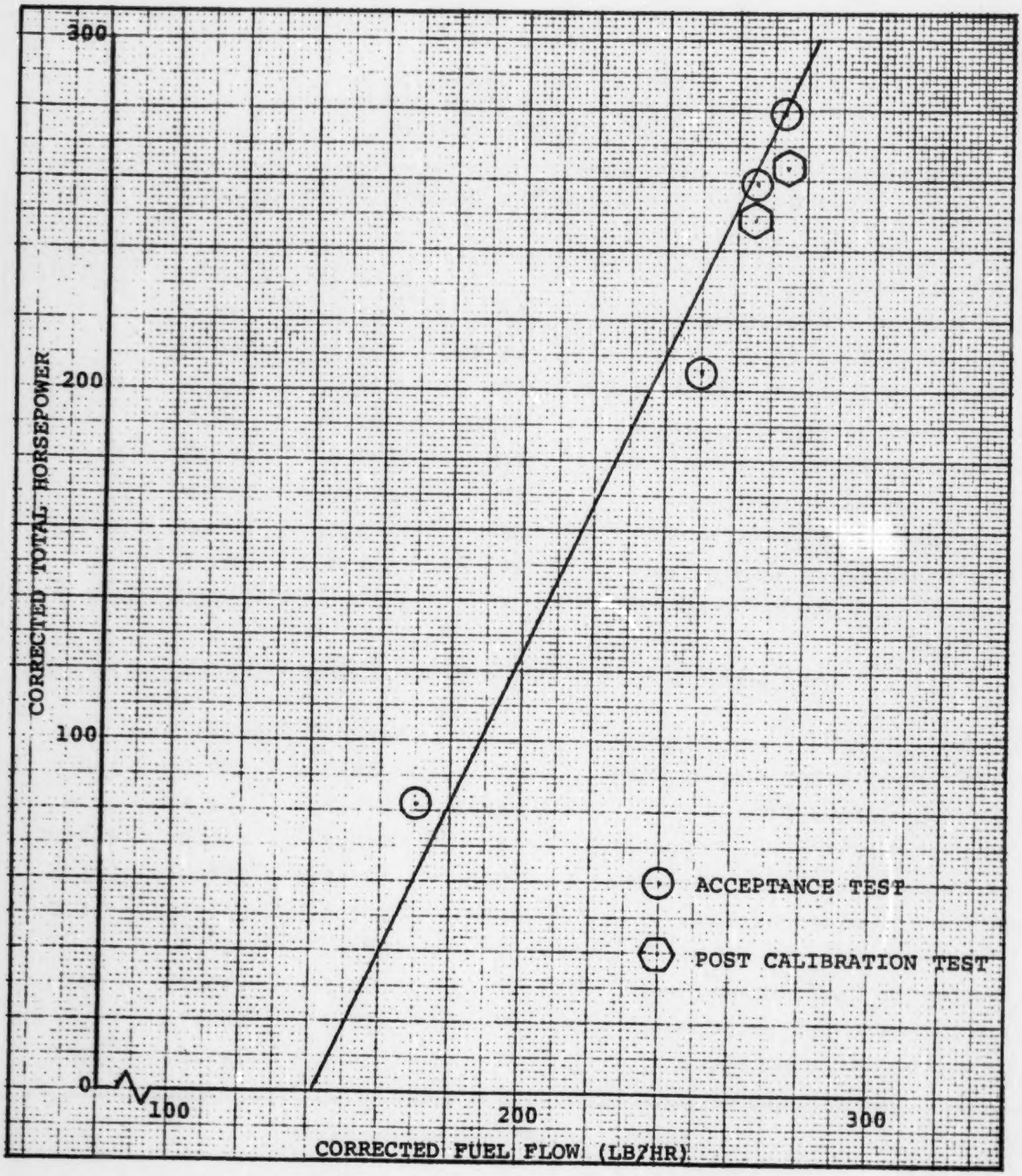
GTCP85-98CK S/N36179
PERFORMANCE COMPARISON BEFORE AND AFTER EMISSION TESTING

Load Point 1 = 0.0 SHP + Extract Bleed-Air to 1150°F TDT

Date of test		5/22/75	6/20/75	ACCEPTANCE REQUIREMENT
Compressor inlet temperature	°F	83.0	92.0	100
Corrected fuel flow	LB/HR	265.1	265.5	
Corrected bleed air temperature	°F	437.0	440.0	428±25
Corrected bleed air pressure	"HgA	99.9	97.7	96.7
Corrected bleed airflow	PPM	128.8	126.2	128.0
Corrected air horsepower	HP	259.1	249.6	- -
Corrected shaft horsepower	HP	0.0	0.0	- -
Corrected total horsepower	HP	259.1	249.6	- -
Exhaust gas temperature	°F	1150.0	1137.0	1150.0

Load Point 2 = 50.0 SHP + Extract Bleed-Air to 1150°F TDT

Date of test		5/22/75	6/20/75	
Compressor inlet temperature	°F	86.0	90.0	100.0
Corrected fuel flow	LB/HR	273.9	274.9	- -
Corrected bleed air temperature	°F	440.0	440.0	434±25
Corrected bleed air pressure	"HgA	104.6	103.6	101.4
Corrected bleed airflow	PPM	113.3	107.6	111.0
Corrected air horsepower	HP	227.9	216.5	- -
Corrected shaft horsepower	HP	50.5	46.2	50.0
Corrected total horsepower	HP	278.4	262.7	- -
Exhaust gas temperature	°F	1150.0	1143.0	1150.0



GTCP85-98CK FUEL FLOW VERSUS HORSEPOWER
BEFORE AND AFTER EMISSION TESTING

FIGURE 5-7

5.2 TPE331-3U-303 Combustor Rig Testing

5.2.1 Combustor Rig Testing at 840 Horsepower

Two baseline tests of an engine rating condition of 840 horsepower, corrected to sea level, 59°F day, were performed at the operating conditions specified in Table 5-2. Test results, performed with and without secondary fuel atomizers functioning, are presented in Tables 5-3 through 5-6. Note that test operating Conditions 4 through 7 were not repeated for "primaries only" operation, since each fuel management system is functioning identically at these conditions.

Tabulated results of turboprop combustor rig testing may be summarized as follows:

(a) Table 5-3 shows the maximum combustor discharge temperature observed with "primaries only" operation to be 2022°F for Condition 16. Test Condition 13 would have a somewhat higher maximum temperature but, as previously stated, this condition required a fuel pressure exceeding facility capabilities. With respect to maximum temperatures, one important fact is that in actual operation of an engine, at a corrected sea level shaft horsepower of 840 over the range of conditions required for this test, would cause certain limiting engine operating temperatures to be exceeded. These temperature limiting criteria are more fully discussed in conjunction with the second series of tests conducted on the TPE331 combustion rig. In conclusion, although the "primaries only" maximum temperatures are higher than the normal fuel delivery system on a point for point basis, these temperatures are not excessively high. This is verified by the fact that test Conditions 7 and 13, for the normal system, have higher maximum temperatures than the "primaries only" configuration.

TABLE 5-2

RIG TEST OPERATING CONDITIONS*

Verification Test Points for Operation on Primary Fuel Atomizers Only

Test Operating Condition	To (°C)	Po (mm)	Power Setting	Humidity
1	15	740 (or 760)	Idle (5%)	Hold constant for each test point
2			1.5 x Idle (7.5%)	
3			2.0 x Idle (10%)	
4			Approach (30%)	
5			Cruise (70%)	
6			Climbout (90%)	
7			Take-off (100%)	
8		500	Idle	
9			1.5 x Idle	
10			2.0 x Idle	
11	-7	740	Idle	
12			1.5 x Idle	
13			2.0 x Idle	
14	33	740	Idle	
15			1.5 x Idle	
16			2.0 x Idle	

*Each conditon determined as a fraction of 840 shp takeoff rating condition referred to sea level, static, 59°F day ($\text{shp}/\sqrt{\theta\delta} = 840$ hp).

TABLE 5-3

TPE331-3U-303 TURBINE INLET TEMPERATURE COMPARISON

Test Operating Condition	Primaries and Secondaries			Primaries Only		
	Pattern Factor	T_4 Max °F	T_4 Avg °F	Pattern Factor	T_4 Max °F	T_4 Avg °F
1	0.317	1403	1145	0.346	1443	1158
2	0.259	1565	1312	0.353	1615	1281
3	0.229	1802	1528	0.434	1970	1475
4	0.13	1458	1366	--	--	--
5	0.131	1758	1654	--	--	--
6	0.123	1945	1804	--	--	--
7	0.119	2031	1885	--	--	--
8	0.275	1438	1200	0.298	1367	1130
9	0.364	1706	1340	0.307	1601	1303
10	0.384	1989	1529	0.379	1949	1505
11	0.332	1234	1000	0.345	1281	1028
12	0.289	1562	1278	0.424	1677	1266
13	0.242	2029	1692	*		
14	0.300	1521	1254	0.335	1528	1236
15	0.312	1717	1396	0.376	1742	1365
16	0.277	1894	1562	0.445	2022	1512

*This point was not taken due to excessive fuel pressure.

TABLE 5-4

TPE331-3U-303 COMBUSTION EFFICIENCY COMPARISON

Test Operating Condition	Primaries and Secondaries			Primaries Only		
	f/a Emissions	f/a Calc	η_{Comb}	f/a Emissions	f/a Calc	η_{Comb}
1	0.0124	0.0125	90.76	0.0113	0.0113	99.38
2	0.0145	0.0150	94.45	0.0132	0.0135	99.70
3	0.0176	0.0180	97.72	0.0162	0.0164	99.83
4	0.0098	0.0096	99.83	--	--	--
5	0.0142	0.0140	99.96	--	--	--
6	0.0169	0.0166	99.98	--	--	--
7	0.0182	0.0179	99.98	--	--	--
8	0.0127	0.0132	94.67	0.0111	0.0111	99.84
9	0.0153	0.0154	94.15	0.0137	0.0139	99.51
10	0.0187	0.0189	97.47	0.0173	0.0174	99.81
11	0.0111	0.011	85.89	0.0099	0.0099	99.23
12	0.0147	0.0149	92.34	0.0133	0.0136	99.66
13	0.0205	0.0210	99.35	*		
14	0.0134	0.0136	92.90	0.0121	0.0122	99.65
15	0.0154	0.0157	95.76	0.0142	0.0135	99.78
16	0.0179	0.0182	97.91	0.0167	0.0166	99.86

*This point was not taken due to excessive fuel pressure.

TABLE 5-5

TPE331-3U-303 EMISSIONS COMPARISON
EMISSION INDEX - LB/1000 LB OF FUEL

Test Operating Condition	Primaries and Secondaries			Primaries Only		
	CO	HC	NO_x	CO	HC	NO_x
1	68.11	87.13	3.052	16.87	2.563	4.57
2	73.10	43.63	3.344	11.52	0.371	4.78
3	73.21	6.34	4.278	6.79	0.094	5.10
4	6.17	0.342	12.381	--	--	--
5	0.898	0.166	13.60	--	--	--
6	0.441	0.150	13.90	--	--	--
7	0.326	0.149	14.24	--	--	--
8	51.36	47.07	2.968	33.71	4.19	3.71
9	67.64	48.57	2.845	18.35	0.724	3.98
10	85.10	6.06	3.604	7.77	0.078	4.41
11	64.18	143.60	2.491	22.76	2.717	4.20
12	79.02	66.11	3,051	12.33	0.557	4.73
13	27.30	0.124	4.836	*		
14	66.84	63.0	3.26	13.38	0.415	4.77
15	78.28	27.35	3.77	8.77	0.107	5.24
16	74.32	3.92	4.45	5.79	0.081	5.38

*This point was not taken due to excessive fuel pressure.

TABLE 5-6

LANDING TAKEOFF CYCLE COMPARISON
(Lb/1000 Hp-Hr-cycle)

Primaries Plus Secondaries (RIG)	Primaries Only (RIG)	Primaries Plus Secondaries (Avg of 6 Engines)	1979 Emissions Standard
HC - 59.57	HC - 1.72	HC - 58.5	HC - 4.9
CO - 48.2	CO - 12.21	CO - 46.5	CO - 26.8
NO_x - 9.59	NO_x - 10.33	NO_x - 8.06	NO_x - 12.9

(b) Although pattern factors, near idle, and average combustor discharge temperatures are higher for the "primaries only" configuration than the normal fuel injection system, Table 5-3 shows that these values are not excessive. Further, being near idle the pattern factors have less importance.

(c) Table 5-4 shows that the fuel-air ratio, calculated from emissions and that actually measured, are within 3 percent of each other. This result indicates that representative exhaust emission samples were taken.

(d) Table 5-4 shows that combustion efficiency increased from 5 to 14 percent for the "primaries only" configuration. Also, normal fuel injection system results from the rig testing compare well with average engine results.

In conclusion, these data indicate that a TPE331 turboprop engine could be operated at 840 corrected shaft horsepower, over the range of ambient test conditions specified, using the "primaries only" fuel injection system for near idle operation. Additionally, this system allows the TPE331 to meet 1979 aircraft emission standards without detrimental effect on combustor performance or engine durability.

5.2.2 Combustion Rig Testing at 706 Horsepower

As explained in subsections 4.2 and 4.3, the turboprop combustor rig testing, listed in Table 5-2, was repeated for a derated 706 maximum corrected shaft horsepower with and without secondary fuel atomizers to prevent turbine interstage overtemperature during subsequent engine testing. Results of this test series is presented in Tables 5-7 through 5-10. The test results generally follow the conclusions from the 840 (maximum) corrected shaft horsepower testing discussed

TABLE 5-7

TPE331-3U-303 INLET TEMPERATURE COMPARISON*

Test Operating Condition	PRIMARIES + SECONDARIES			PRIMARIES ONLY		
	P.F.	T_4 Max °F	T_4 Avg °F	P.F.	T_4 Max	T_4 Avg
1	0.476	1342	1016	0.327	1394	1132
2	0.417	1478	1140	0.338	1547	1240
3	0.365	1619	1274	0.324	1699	1364
4	0.126	1441	1354	--	--	--
5	0.129	1687	1571	--	--	--
6	0.102	1798	1694	--	--	--
7	0.093	1884	1781	--	--	--
8	0.400	1375	1077	0.316	1386	1133
9	0.392	1510	1178	0.328	1540	1241
10	0.480	1791	1318	0.347	1773	1401
11	0.484	1185	894	0.378	1250	988
12	0.483	1302	973	0.358	1360	1079
13	0.416	1811	1365	0.397	1908	1449
14	0.440	1472	1133	0.325	1498	1220
15	0.436	1633	1247	0.309	1622	1325
16	0.435	1777	1348	0.333	1800	1440

*Based on derated 706 shp/$\sqrt{\theta\delta}$ (maximum).

TABLE 5-8

TPE331-3U-303 COMBUSTION EFFICIENCY COMPARISON*

Test Operating Condition	PRIMARIES + SECONDARIES			PRIMARIES ONLY		
	f/a emis.	f/a calc.	η_{comb}	f/a emis.	f/a calc.	η_{comb}
1	0.0116	0.0119	90.09	0.0110	0.0110	98.71
2	0.0133	0.0137	93.18	0.0125	0.0126	99.26
3	0.0152	0.0160	95.75	0.0145	0.0146	99.65
4	0.0095	0.0093	99.83	--	--	--
5	0.0128	0.0128	99.95	--	--	--
6	0.0148	0.0146	99.97	--	--	--
7	0.0164	0.0159	99.98	--	--	--
8	0.0119	0.0122	96.59	0.0113	0.0114	97.81
9	0.0139	0.0141	95.50	0.0130	0.0129	98.70
10	0.0167	0.0169	96.57	0.0153	0.0155	99.38
11	0.0102	0.0103	87.09	0.0094	0.0093	98.39
12	0.0111	0.0117	88.80	0.0106	0.0106	99.01
13	0.0176	0.0180	97.42	0.0164	0.0166	99.76
14	0.0128	0.0129	94.16	0.0118	0.0118	99.44
15	0.0146	0.0148	95.83	0.0134	0.0135	99.65
16	0.0165	0.0168	97.11	0.0152	0.0163	99.77

*Based on derated 706 shp/$\sqrt{\theta}\delta$ (maximum).

TABLE 5-9

TPE331-3U-303 EMISSIONS COMPARISON*
Emission Index - Lb/1000 Lb Fuel

Test Operating Condition	Primaries and Secondaries			Primaries Only		
	CO	HC	NOX	CO	HC	NOX
1	64.05	95.81	2.95	25.41	7.85	4.50
2	67.88	59.51	2.09	19.29	3.29	4.88
3	83.73	26.05	4.06	12.25	0.77	5.23
4	6.30	0.26	13.69	--	--	--
5	1.63	0.11	14.40	--	--	--
6	1.02	0.10	14.54	--	--	--
7	0.73	0.04	14.79	--	--	--
8	47.28	26.22	3.38	40.15	14.23	3.61
9	58.23	35.66	3.27	30.06	6.76	3.75
10	79.73	17.71	3.57	19.46	1.83	4.20
11	63.66	130.1	2.82	28.55	10.73	4.11
12	68.86	109.2	3.08	22.06	5.38	4.53
13	73.87	9.64	4.20	9.18	0.26	5.26
14	61.34	50.11	3.82	17.52	1.72	5.18
15	74.04	27.66	4.14	12.32	0.65	4.94
16	80.89	11.29	4.29	8.85	0.22	5.25

*Based on derated 706 shp/$\sqrt{\theta\delta}$ (maximum).

TABLE 5-10

LANDING TAKEOFF CYCLE COMPARISON
(Lb/1000 Hp-Hr-Cycle)

840 S.L. Corrected SHP

Primaries Plus Secondaries (RIG)	Primaries Only (RIG)	Primaries Plus Secondaries (Avg of 6 Engines)	1979 Emissions Standard
HC - 59.57	HC - 1.72	HC - 58.5	HC - 4.9
CO - 48.2	CO - 12.21	CO - 46.5	CO - 26.8
NO_x - 9.59	NO_x - 10.33	NO_x - 8.06	NO_x - 12.9
706 S.L. Corrected SHP			
HC - 74.77	HC - 5.70		HC - 4.9
CO - 52.19	CO - 20.31		CO - 26.8
NO_x - 11.08	NO_x - 11.98		NO_x - 12.9

above. Table 5-7 indicates the maximum temperature observed for operation on "primaries only" to be 1908°F for Condition 13. This temperature, along with the observed pattern factor and average combustor discharge temperature, is within safe engine operating limits.

A 1 to 2 percent decrease in combustion efficiency, at the near idle conditions, was noted for the "primaries only" configuration from the 840 shp test to the 706 shp test. This trend was reflected as a general increase in CO and HC emission indices for the 706 shp test. This was expected since fuel flows and pressures are lower, and combustion loadings are higher for the derated power testing.

Comparing the Landing Takeoff (LTO) cycle emissions with the 1979 emission standards (Table 5-10) shows that emissions from the "primaries only" mode of operation, for derated testing, are somewhat higher than the maximum rated condition test, and the 1979 HC standard is exceeded. This was expected since the total horsepower factor was lower, and combustion efficiency was 1-2 percent lower, than in maximum rated power testing. In summary:

- The TPE331-3U-303, operating on "primaries only" at idle, can meet the 1979 EPA P2 turboprop standards at the rated 840 shp/$\sqrt{\theta\delta}$ load condition.

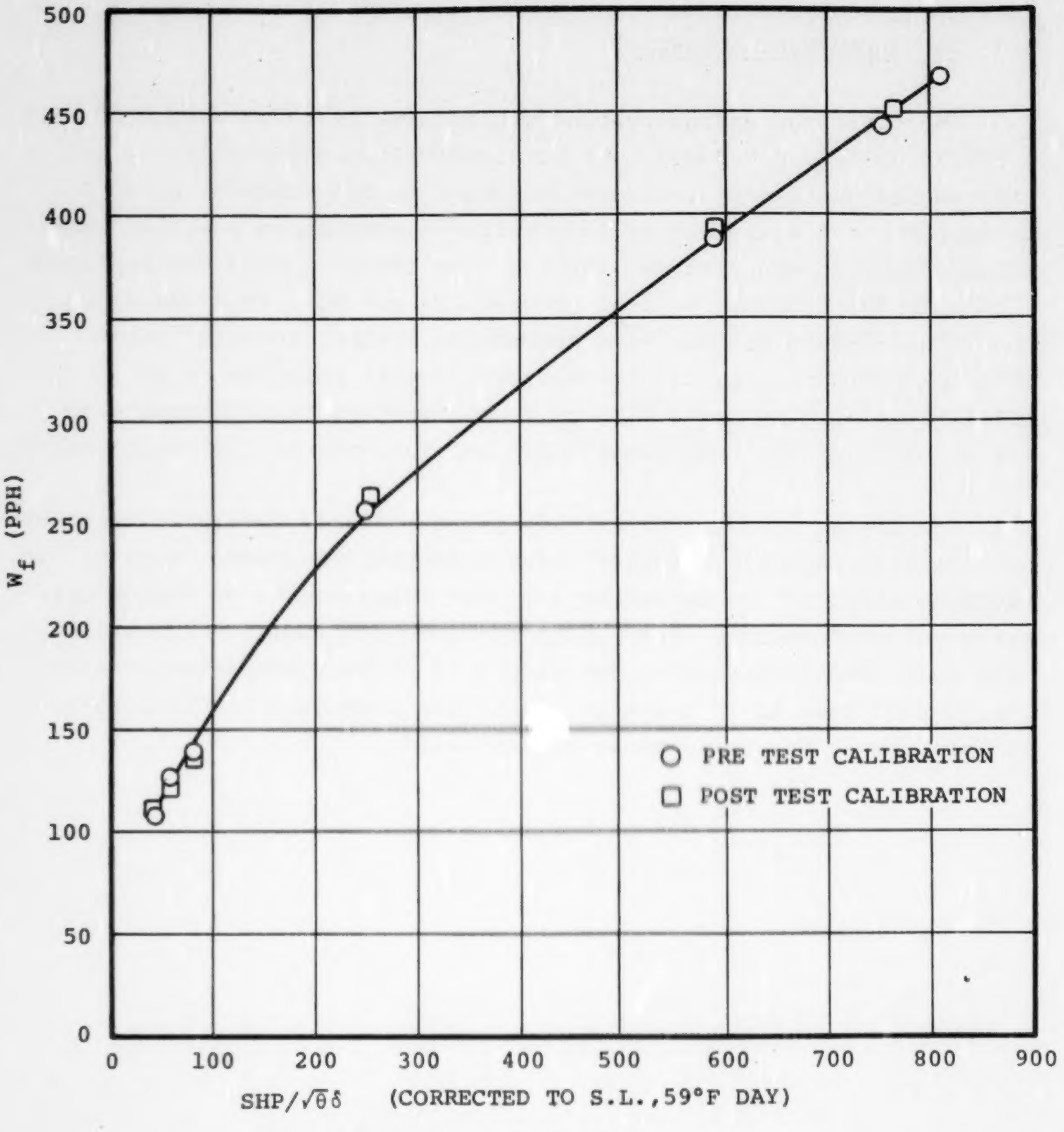
- The engine can be safely operated over the test conditions of Table 4-10 at a reduced load condition of 706 shp/$\sqrt{\theta\delta}$.

- Engine and rig tests reflect good agreement relative to comparing emissions levels.

5.3 Turboprop Engine Testing

The turboprop engine testing was originally to be conducted with a TPE331-3U-303, S/N 00304. As previously stated in Section 4.3.1, this engine sustained considerable damage to the rotating group due to support test equipment failure during installation checkout tests. In an effort to expedite the testing, the TPE331-3U-303 was replaced with a TPE331-5-251M. No test program changes were required since the TPE331-5-251M had the same combustion system, internal aerodynamic configuration, and thermodynamic cycle performance as the TPE331-3U-303. The major differences between the two engines were the location of the compressor inlet and rotation of the output shaft.

The Engine (Model TPE331-5-251M) successfully completed the test program with only minor engine instrumentation problems. None of the problems affected the emissions sampling measurements or engine operation and performance. Pre- and post-test performance calibrations were conducted to determine the extent of performance deterioration. The plotted results of these two tests are presented in Figure 5-8. The plot shows tno performance deterioration.



FUEL FLOW VS. CORRECTED S.L.,59°F
SHAFT HORSEPOWER

FIGURE 5-8

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Gaseous Emissions Sample Transport Time

The two-second gaseous emissions sample transport time is considered restrictive since the maximum sample line length (80 feet with an inner diameter of 0.250 inch) would have a transport time of approximately 10 seconds for a representative sample flow rate of 10 cubic feet per second. Although the sample flow rate could be increased by bypassing the additional flow, this technique is limited by capacity of the sampling equipment pumps and the corresponding increased pressure drop losses. Further, a minimum sample flow rate of 50 cubic feet per second would be required to meet the transport time specification for the sample line described. This is beyond the capacity of most emissions sample equipment pumps.

6.1.2 APU Engine Testing

- APU testing was conducted without major incident with all required emissions data inspected graphically, reduced, and transmitted to Calspan Corporation.

- The method utilized for calculating bleed-air equivalent horsepower creates problems in determining engine load conditions due to the varying inlet ambient conditions. Bleed-air mass flow, and air specific heat, are dependent on ambient conditions at the engine inlet. If compressor discharge temperature is reduced by increasing simulated humidity, the effect is to reduce the equivalent air horsepower. To maintain constant corrected total horsepower, mass flow through the bleed-air system must be increased. Thus, maintaining a constant corrected total horsepower, over the range of inlet ambient conditions tested, necessitated readjustments and calculations to set up the required engine power settings.

- Power setting requirements for measuring APU emissions can be ambivalent relative to typical APU load-cycle operation in airline service. For example, ambient test Conditions 4 and 5 meet the maximum-load condition specifications defined in the 40 CFR 87.63. This is possible, because maximum-load can be satisfied with an unlimited number of bleed-air/shaft power (combination) loads. Ambiguity exists because the "maximum-load condition" can be related to aircraft installation power output, or engine manufacturers rated power output, which are usually not the same. As a result, the generalized load condition specifications in the Federal Register permit combustor parameters to vary considerably while power output remains within specifications. The "correction factor", as defined for the APU, may therefore apply only for the range of power settings actually tested.

- Slight deterioration in APU engine performance was observed from a post-calibration test. A deterioration of 1 to 2 percent was attributed to foreign object damage and normal wear. The amount of performance degradation was considered insignificant.

6.1.3 TPE331 Combustor Rig Testing

- The combustor rig tests verified that the "primary fuel atomizers only" fuel management system could be safely used in the turboprop engine, over the range of ambient conditions required, without adversely affecting component performance.

- Combustor rig tests indicated good agreement, relative to gaseous emission levels, with previously sampled TPE331 engines.

- The TPE331 (840 shp model), operating on "primaries only" at taxi idle, can meet the 1979 EPA P2 class turboprop emission standards at a rated 840 shp/$\sqrt{\theta\delta}$.

6.1.4 TPE Turboprop Engine Testing

- After substitution of Model TPE331-5-251M for TPE331-3U-303, engine testing was conducted without major incident. All required data was graphically inspected, reduced, and transmitted, in an acceptable form, to Calspan for further analyses.

- The TPE331-5-251M turboprop indicated no performance deterioration during testing.

- The landing take-off (LTO) cycle emissions values indicated that the TPE331-5-251M, operating on "primaries only" at taxi idle, can meet the 1979 EPA P2 class turboprop emission standards at all ambient test conditions.

6.2 Recommendations

The following recommendations are based on test program experience:

- It is recommended that consideration be given to eliminate extreme high and low temperatures and high humidity test conditions in future work. These points tend to result in vapor condensation or localized icing unless a disproportionately large amount of time and care are taken in setting up the test conditions.

- It is recommended that additional engine testing be conducted on low and high bypass ratio thrust engines, additional power classes of the turboprop engine, and additional power classes and operating conditions of APUs. This testing is necessary since the applicability of ambient correction factors, to emissions levels from this program, to other engine classes and other types of gas turbine engines is not known.

- It is recommended that studies of an APU duty cycle, and thermodynamic cycle, be performed to establish pertinent test conditions for emission sampling.

- It is recommended that the gaseous emission sample transport time be increased to a maximum of 10 seconds.

- It is recommended that the CO and CO_2 sample system be permitted to have a water trap for taking "dry" measurements only. This system would have a two-fold advantage:

(1) The non-dispersive infrared equipment would be less subject to water-related interference problems.

(2) Condensation would not form in areas that are difficult to heat, such as flowmeters. This is particularly a problem with water-injected engines.

Preliminary test data indicates that the difference between "wet" and "dry" CO and CO_2 readings are less than instrumentation reproducibility (±1 to 2 percent).

Alternatively, allowing the system to use a water trap, while the engine is stabilizing on condition, then by-pass the trap when taking a data point would minimize condensation intake.

APPENDIX I

EMISSIONS ANALYZERS PRINCIPLES OF OPERATION

A. ANALYZER INSTRUMENTATION

This section reviews the gas analyzers and their principles of operation as used to conduct emissions measurements at AiResearch facilities.

A.1 Heated Hydrocarbon Analyzer (Beckman Model 402)

The hydrocarbon analyzer, Figure I-1, is designed to measure the total hydrocarbon contents of exhaust emissions from gasoline, diesel, gas turbine, and jet engines. The analysis is based on flame ionization, a highly sensitive detection method.

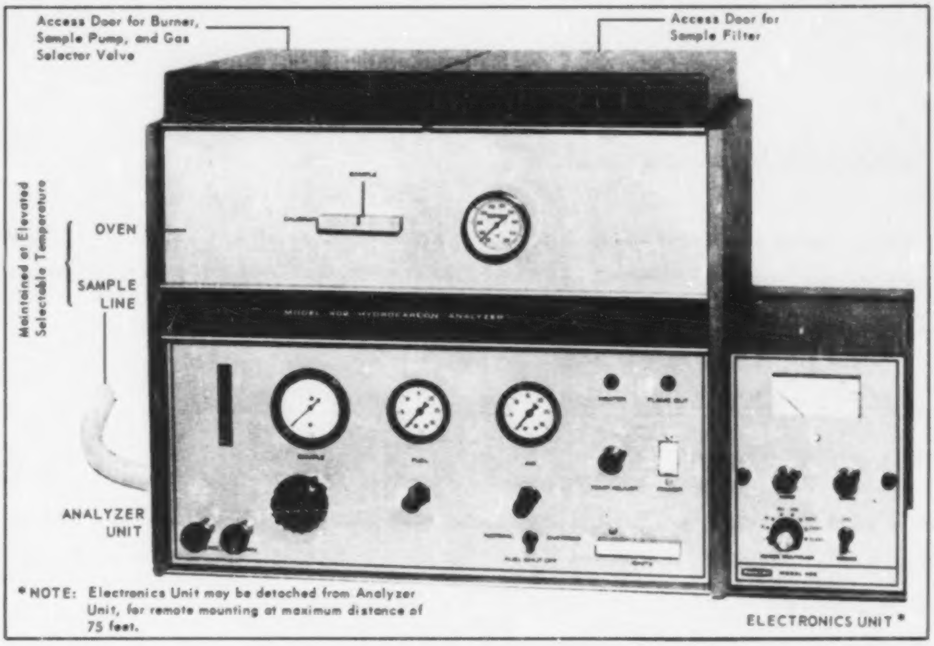
The instrument consists of:

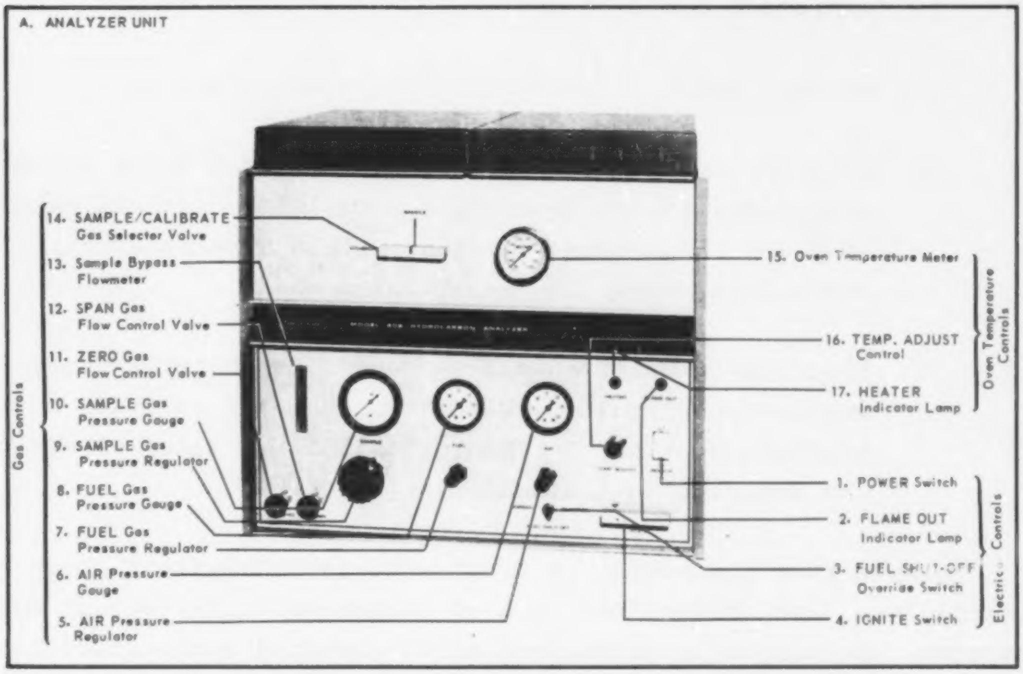
(1) Heated, temperature-controlled sample line.

(2) Analyzer unit, incorporating a flame-ionization detector and associated sample-handling system, with critical sample-handling components contained within a temperature-controlled oven.

(3) Electronics unit, containing an electrometer amplifier and associated circuitry, readout meter, and recorder output provisions. The electronics unit is attached directly to the analyzer unit as shown in Figure I-1.

Sample from the source is drawn into the analyzer through the sample line. To prevent the loss of higher-molecular-weight hydrocarbons, the sample is maintained at an elevated temperature during its passage through the sample line and the interior of the analyzer. Temperature setpoint for the sample line and the analyzer oven will be approximately 329°F for the tests carried out according to the plan.


Access Door for Burner, Sample Pump, and Gas Selector Valve
Access Door for Sample Filter
Maintained at Elevated Selectable Temperature
OVEN
SAMPLE LINE
ANALYZER UNIT
MODEL 402 HYDROCARBON ANALYZER
*NOTE: Electronics Unit may be detached from Analyzer Unit, for remote mounting at maximum distance of 75 feet.
ELECTRONICS UNIT *


A. ANALYZER UNIT
Gas Controls
14. SAMPLE/CALIBRATE Gas Selector Valve
13. Sample Bypass Flowmeter
12. SPAN Gas Flow Control Valve
11. ZERO Gas Flow Control Valve
10. SAMPLE Gas Pressure Gauge
9. SAMPLE Gas Pressure Regulator
8. FUEL Gas Pressure Gauge
7. FUEL Gas Pressure Regulator
6. AIR Pressure Gauge
5. AIR Pressure Regulator
15. Oven Temperature Meter
Oven Temperature Controls
16. TEMP. ADJUST Control
17. HEATER Indicator Lamp
1. POWER Switch
Electrical Controls
2. FLAME OUT Indicator Lamp
3. FUEL SHUT-OFF Override Switch
4. IGNITE Switch
MODEL 402 HYDROCARBON ANALYZER

HYDROCARBON ANALYZER (BECKMAN MODEL 402)
(COURTESY BECKMAN INSTRUMENTS, INC.)

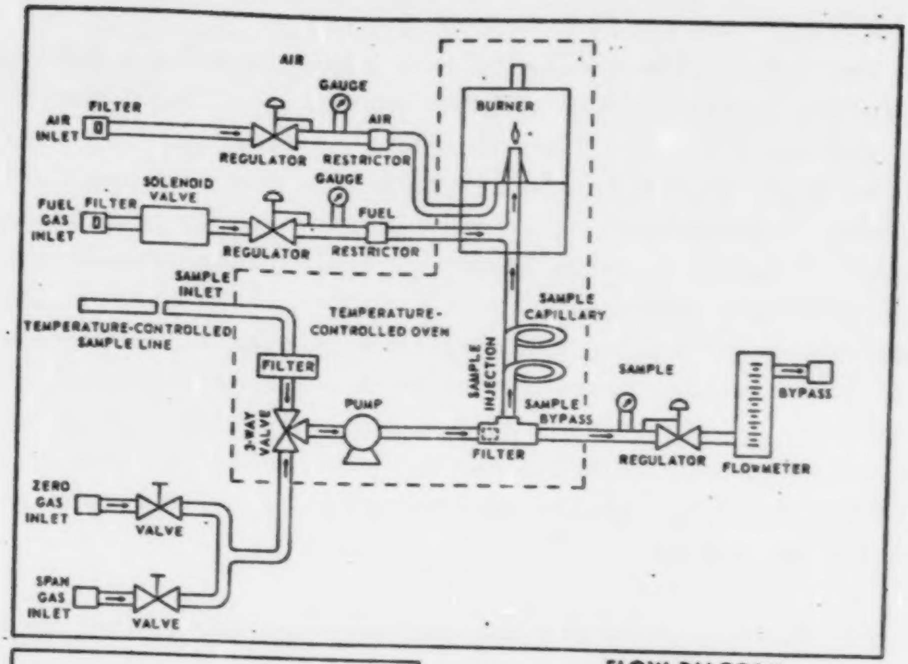
FIGURE I-1

MP-30224

The hydrocarbon sensor is in a burner where a regulated flow of sample gas passes through a flame sustained by regulated flows of a fuel gas and air. The flame formed when fuel gas (hydrogen diluted with an inert gas) burns in air contains an almost negligible number of ions. Introduction of traces of hydrocarbons into such a flame, however, produces a large amount of ionization. Within the flame, the hydrocarbon components of the sample stream undergo ionization, producing electrons and positive ions. Polarized electrodes collect these ions, causing current to flow through measuring circuitry located in the electronics unit. The ionization current is proportional to the rate at which carbon atoms enter the burner and is therefore a measure of the concentration of hydrocarbons in the original gas sample.

The flow diagrams for the analyzer and burner are shown in Figure I-2. A stainless-steel bellows-type positive displacement pump of four ct ft/hr capacity draws the sample into the analyzer and through a glass fiber filter that removes particulate matter. The sample is then supplied to the burner under positive pressure. An internal sample-bypass arrangement provides high-velocity sample flow through the analyzer, thus minimizing system response time. A front-panel flowmeter indicates bypass flow. Since the ionization level is related to the flow rate of sample through the flame, pressure must be set to read a sample pressure identical to the calibration gas pressure. The analyzer has rear-panel inlet ports for connection of suitably pressurized zero and span standard gases. Flow of each standard gas is controlled by a corresponding front-panel needle valve. A front-panel three-way valve permits selection of either the actual sample or the desired standard gas (i.e., "zero gas" or "span gas" referenced in Figure I-2) used in calibrating the instrument.

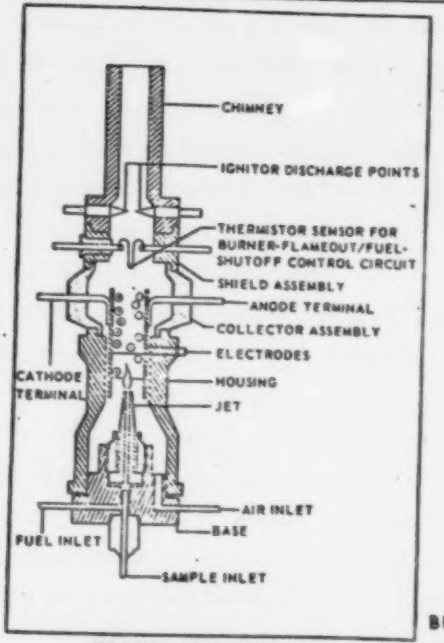
The oven, which uses air-bath heating, is maintained at the selected temperature by a solid-state temperature controller utilizing a thermistor sensor. A vertical partition divides the oven into


AIR
FILTER
AIR INLET
GAUGE
AIR
REGULATOR
RESTRICTOR
BURNER
SOLENOID VALVE
GAUGE
FUEL GAS INLET
FILTER
FUEL
REGULATOR
RESTRICTOR
SAMPLE INLET
TEMPERATURE-CONTROLLED SAMPLE LINE
TEMPERATURE-CONTROLLED OVEN
SAMPLE CAPILLARY
SAMPLE INJECTION
FILTER
3-WAY VALVE
PUMP
SAMPLE BYPASS
FILTER
SAMPLE
REGULATOR
FLOWMETER
BYPASS
ZERO GAS INLET
VALVE
SPAN GAS INLET
VALVE

FLOW DIAGRAM

SPECIFICATIONS

Analysis Temperature	Adjustable from 200°F to 400°F
Line Voltage	107-127 VAC 50/60 Hz, 1000 watts max.
Ambient Operational Temperature	32°F to 110°F
Ambient Operational Humidity	95% R.H.
Potentiometric Output	10 mV, 100 mV, 1V
Sensitivity	5 ppm to 10% full scale as CH_4 with H_2/N_2 or H_2/He Fuel
Ranges	X1, X5, X10, X50, X100, X500, X1000, X5000 with continuous electronic span adjustment
Response	Less than 1 second for 90% of final reading (with CH_4 from analyzer input without sample probe)
Electronic Stability	±1% full scale/24 hrs. with less than 10° ambient temperature change
Repeatability	±1% full scale for successive samples
Temperature Controlled Probe	10 ft. length, teflon surface in contact with sample (proportional temperature controlled and adjustable from 200°F to 400°F)


CHIMNEY
IGNITOR DISCHARGE POINTS
THERMISTOR SENSOR FOR BURNER-FLAMEOUT/FUEL-SHUTOFF CONTROL CIRCUIT
SHIELD ASSEMBLY
ANODE TERMINAL
COLLECTOR ASSEMBLY
ELECTRODES
CATHODE TERMINAL
HOUSING
JET
AIR INLET
BASE
FUEL INLET
SAMPLE INLET

BURNER DIAGRAM

HEATED HYDROCARBON ANALYZER SPECIFICATIONS AND DIAGRAMS (FIGURES COURTESY OF BECKMAN INSTRUMENTS, INC.)

FIGURE I-2

two compartments with separate doors. The left-hand compartment contains the burner, the sample pump, and the three-way gas-selector valve. The right-hand compartment contains only the sample filter and permits access to the filter without disturbing temperature equilibrium of the other elements.

Within the analyzer, the fuel gas is routed to the burner through a solenoid valve controlled by the burner-flameout/fuel-shutoff circuitry. A thermistor sensor continuously monitors the status of the burner flame. In event of flameout, the valve closes to stop the flow of fuel gas; simultaneously, a front-panel indicator illuminates to alert the operator.

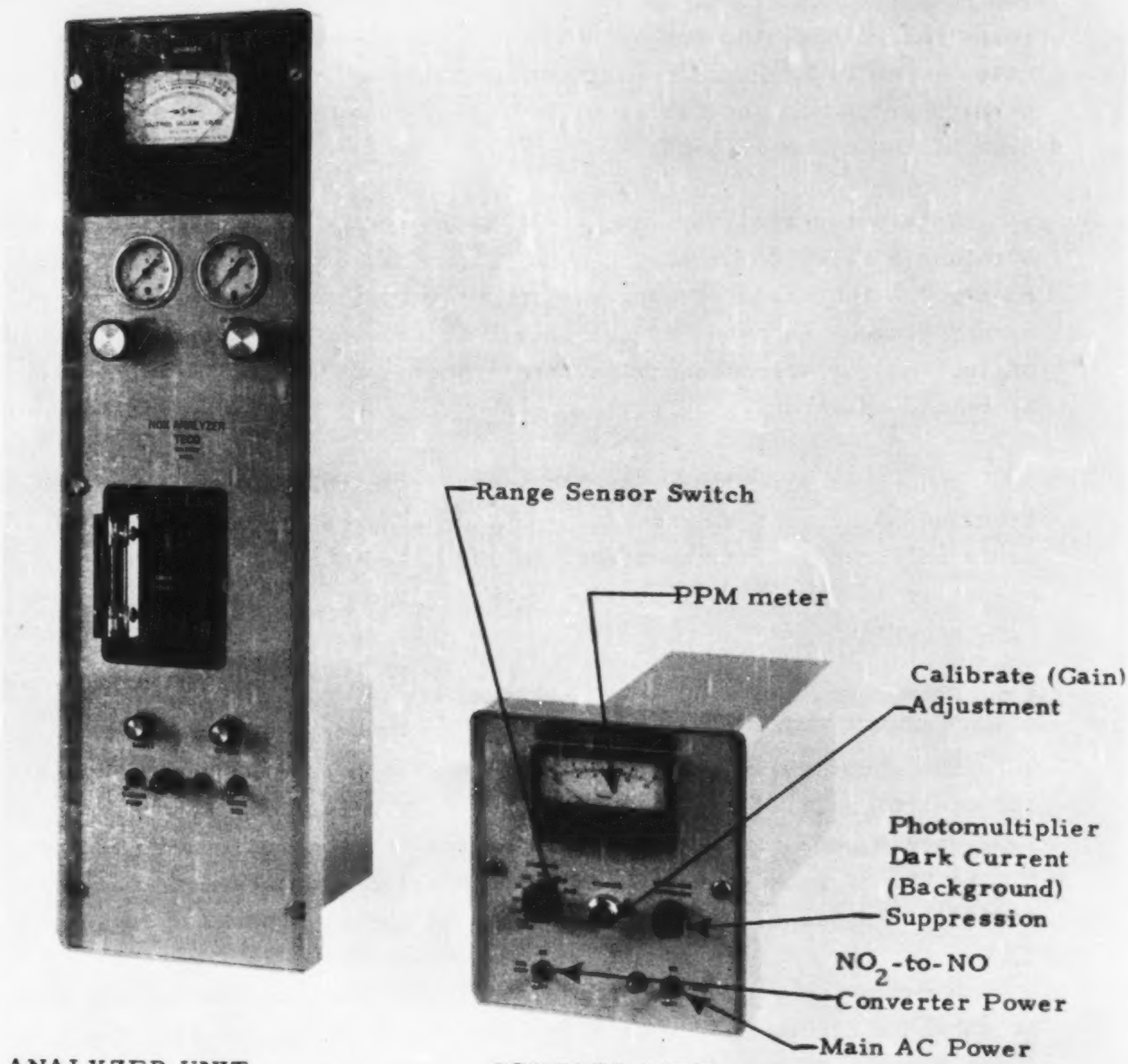
The electronics unit has front-panel controls for range selection and adjustment of zero and span. Readout is on a front-panel meter calibrated linearly from 0 to 100. In addition, a selectable output of 10 mv, 100 mv, or 1 volt is available to drive a voltage-type recorder.

A.2 Chemiluminescent/NO - NO_x Analyzer

The chemiluminescent analyzer is packaged as four separate units: (1) control unit, (2) an analyzer unit, (3) a reaction chamber mechanical vacuum pump, and (4) a converter for the thermal conversion of NO_2 to NO. For these tests, a Thermo Electron Corporation analyzer model 10A was used, which was operated in the NO_x and NO modes.

A typical arrangement of the Model 10A chemiluminescent analyzer is shown in Figure I-3. Other equipment needed for use with the analyzer are the NO and NO_2 standard gases, an oxygen source for the ozone generator, and an accumulator and suitable sample bypass pump to provide two to two and one-half cu ft/hr sample flow.

The control unit contains the switch for selection of sensitivity from seven available full-scale ranges (10, 25, 100, 250, 1000, 2500, and 10,000 ppm) and potentiometers which provide for instrument calibration.


NOX ANALYZER
TECO
Range Sensor Switch
PPM meter
Calibrate (Gain)
Adjustment
Photomultiplier
Dark Current
(Background)
Suppression
NO_2-to-NO
Converter Power
Main AC Power

ANALYZER UNIT

CONTROL UNIT

MODEL 10 CHEMILUMINESCENT ANALYZER
(CONTROL AND ANALYZER UNITS)
MODEL 10A CHEMILUMINESCENT ANALYZER
(CONTROL AND ANALYZER UNITS)

MP-30252

FIGURE I-3

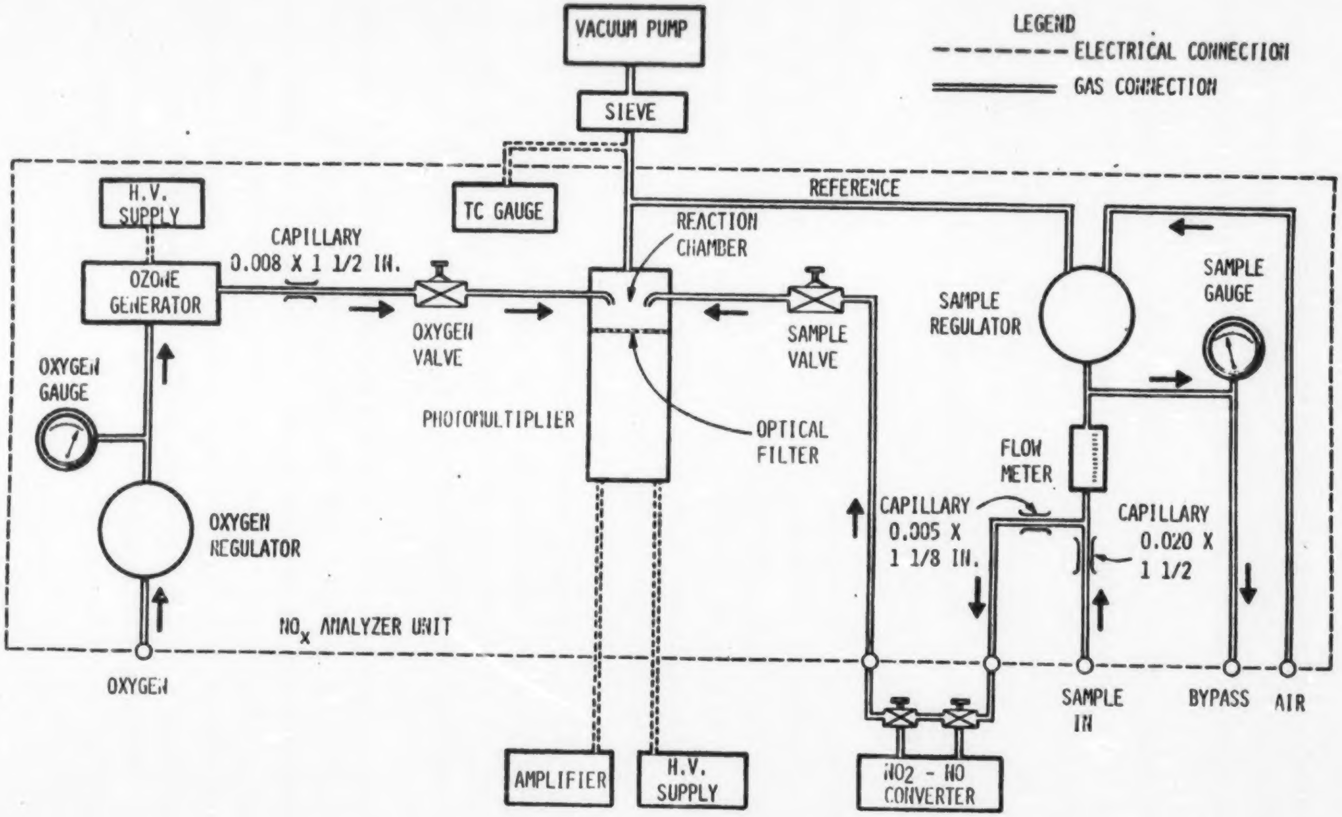
The analyzer unit contains the reaction chamber, the photomultiplier tube, the ozonator, the ozonator power supply, the oxygen and gas sample lines, capillaries, and pressure regulators.

Figure I-4 presents a schematic drawing of the entire chemiluminescent instrument with the portion inside the dashed rectangle representing the analyzer unit. The heart of the analyzer is the cylindrical reaction chamber where sample gas containing NO molecules mixes with O_3 molecules from the ozonator. Electronically excited NO_2 molecules are created that emit light (chemiliminescence) as the orbital electrons decay to their ground states.

The chemiluminescence is monitored through an optical filter by a high sensitivity photomiltiplier positioned at one end of the reactor. The filter-photomultiplier combination responds to light in a narrow wavelength band unique to the desired electron decay. Sample flow is controlled so that the output from the photomultiplier is linearly proportional to the NO concentration.

Oxygen, O_2, enters the analyzer unit, passing through a pressure regulator that is used to regulate the flow rate, and enters the ozonator. A fraction of the O_2 is converted to O_3, and the mixture passes through an orificing glass capillary to the reaction chamber.

Sample gas enters the instrument, passing through another glass capillary, and is bled off to the reaction chamber. That portion of the entering sample not diverted to the reaction chamber passes through a front panel flowmeter adjusted to two standard cubic feet per hour and a regulator to the instrument exhaust system. A bypass pump is used to pull the sample through the instrument. That portion of the entering gas sample diverted toward the reaction chamber is directed to the rear of the analyzer unit, where the sample gas will


VACUUM PUMP
SIEVE
LEGEND
ELECTRICAL CONNECTION
GAS CONNECTION
TC GAUGE
REFERENCE
H.V. SUPPLY
OZONE GENERATOR
CAPILLARY 0.008 X 1 1/2 IN.
OXYGEN VALVE
REACTION CHAMBER
SAMPLE VALVE
SAMPLE REGULATOR
SAMPLE GAUGE
OXYGEN GAUGE
PHOTOMULTIPLIER
OPTICAL FILTER
FLOW METER
OXYGEN REGULATOR
CAPILLARY 0.005 X 1 1/8 IN.
CAPILLARY 0.020 X 1 1/2
NO_x ANALYZER UNIT
OXYGEN
SAMPLE IN
BYPASS
AIR
AMPLIFIER
H.V. SUPPLY
NO_2 - NO CONVERTER

CHEMILUMINESCENT ANALYZER

FIGURE I-4

enter the converter if the instrument is operating in the NO_x mode (i.e., NO - NO_2 mixture mode). As explained below, use of the converter is unnecessary if the instrument is operating in the NO mode.

The basic chemiluminescent analyzer is only sensitive to NO molecules, as opposed to NO_2 molecules, since O_3 does not react with NO_2 to create chemiluminescence. Therefore, to measure NO_x (NO_2 + NO), the NO_2 must first be converted to NO. The conversion is accomplished by passing the sample gas through the converter, a thermally-insulated resistance-heated stainless steel coil at 1292°F. With the application of heat, NO_2 molecules in the sample gas are reduced to NO molecules. Two three-way valves located on the front of the converter direct the sample gas either through the converter to measure NO_x or past the converter to measure NO.

A mechanical vacuum pump is supplied to evacuate the analyzer reaction chamber to pressures in the 12 torr range. A metal bellows hose connects to a molecular sieve installed above the mechanical pump. The purpose of this sieve is to absorb O_3 in order to prevent breakdown of the pump oil.

The gas sample is pulled through the instrument by a small dynapump, after which it is exhausted to ambient. This pump improves the overall system response by moving the flow in the main sample line by about 2.0 liters per minute, while each instrument in the analyzer group removes flow from the main sample line at a much lower rate.

A.4 Non-Dispersive Infrared (NDIR) Analyzers for CO - CO_2

To measure the differential absorption of infrared energy, this instrument employs a double-beam optical system contained in the analyzer section. A simplified functional diagram and instrument specifications are shown in Figure I-5.

Two infrared sources are used, one for the sample energy-beam, the other for reference energy-beam. The beams are blocked simultaneously ten times per second by the chopper, a two-segmented blade rotating at five revolutions per second. In the unblocked condition, A of Figure I-5 each beam passes through the associated cell and into the detector.

The sample cell is a flow-through tube that receives a continuous stream of sample. The reference cell is a sealed tube filled with a reference gas. This gas is selected for negligible absorption of infrared energy of those wavelengths absorbed by the sample component of interest.

The detector consists of two sealed compartments separated by a flexible metal diaphragm. Each compartment has an infrared-transmitting window, to permit entry of the corresponding energy-beam. Both chambers are filled, to the same sub-atmospheric pressure, with the vapor of the component of interest. Therefore, each chamber will absorb infrared energy from its source and will respond.

The response of the two detector chambers differs, since in operation the presence of the infrared-absorbing component of interest in the sample streams leaves less energy available for the corresponding detector chamber. There is, thus, a difference in energy levels between the sample (containing the component of interest) and the reference (non-absorbing) sides of the system. This energy difference results in the following sequence of events.

SPECIFICATIONS

MAXIMUM ZERO DRIFT:
±1% of full scale per 8 hours.

MAXIMUM SPAN DRIFT:
±1% of full scale per 24 hours.

SENSITIVITY:
0.5% of full scale.

ACCURACY:
±1%.

AMPLIFIER RESPONSE SPEED:
90% response in 0.5 second.

AMBIENT TEMPERATURE RANGE:

IR315, IR315L, −20° to +120°F.

OUTPUT (Options Available):
Current output—0 to 5 ma into 500 ohms maximum.
Voltage output—Adjustable to match any potentiometric recorder having a span of between 1 and 100 mv.

VOLTAGE AND FREQUENCY (Options Available):
115 ±15 volts, 60 ±0.5 Hz (cps); or
115 ±15 volts, 50 ±0.5 Hz (cps).

MAXIMUM POWER CONSUMPTION

IR315, 530 watts; IR315L, 640 watts.

MAXIMUM SEPARATION OF AMPLIFIER CONTROL SECTION AND ANALYZER SECTION
500 feet.

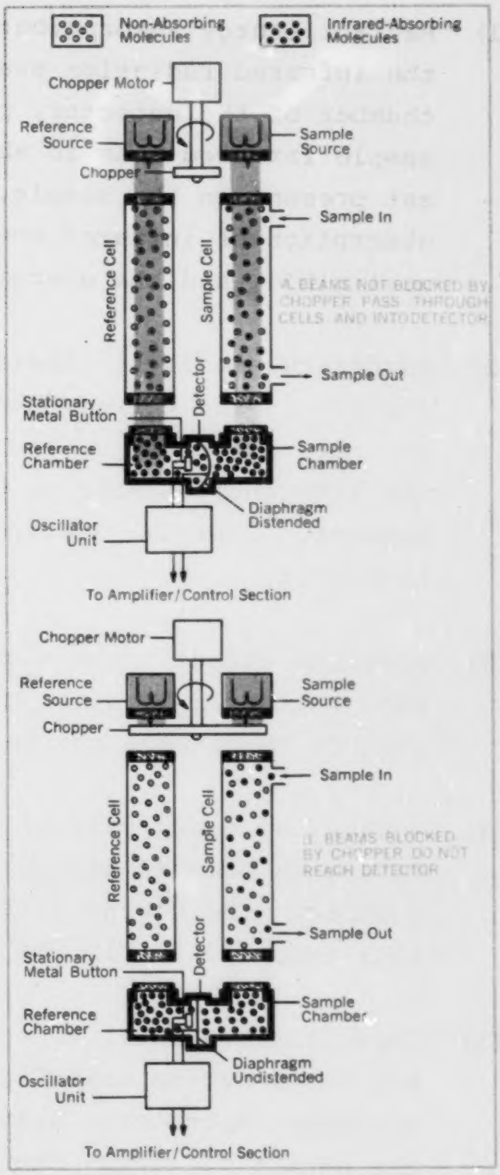
SHIPPING WEIGHT:

IR315S, 115 pounds; IR315L, 170 pounds.

NET WEIGHT:

IR315S, 85 pounds; IR315L, 120 pounds.

CATALOG NUMBERS:
95700 Model IR315S Infrared Analyzer (Short Path)
95701 Model IR315L Infrared Analyzer (Long Path)


Non-Absorbing Molecules
Infrared-Absorbing Molecules
Chopper Motor
Reference Source
Sample Source
Chopper
Sample In
Reference Cell
Sample Cell
A. BEAMS NOT BLOCKED BY CHOPPER PASS THROUGH CELLS AND INTO DETECTOR
Sample Out
Stationary Metal Button
Detector
Reference Chamber
Sample Chamber
Diaphragm Distended
Oscillator Unit
To Amplifier/Control Section
Chopper Motor
Reference Source
Sample Source
Chopper
Sample In
Reference Cell
Sample Cell
B. BEAMS BLOCKED BY CHOPPER DO NOT REACH DETECTOR
Sample Out
Stationary Metal Button
Detector
Reference Chamber
Sample Chamber
Diaphragm Undistended
Oscillator Unit
To Amplifier/Control Section

NON-DISPERSIVE INFRA-RED ANALYZER
SECTION SPECIFICATIONS AND
FUNCTIONAL DIAGRAM

FIGURE I-5

(1) Radiant energy absorption: In the sample cell through which the infrared radiation passes on the way to the sample chamber of the detector, part of the original energy of the sample infrared beam is absorbed by the component of interest present in the sample. In the reference cell, however, absorption of infrared energy from the reference beam is negligible, and the energy of this reference beam is higher.

(2) Temperature effect: Inside the detector, each beam heats the gas in the corresponding chamber, because of absorption of infrared energy by the component of interest. The gas in the reference chamber is heated to a higher temperature, however, since the energy available from the reference beam is higher.

(3) Pressure effect: The higher gas temperature in the reference chamber raises the pressure of this compartment above that of the sample chamber.

(4) Mechanical energy effect: The higher gas pressure in the reference chamber distends the diaphragm toward the sample chamber. The energy difference between the two chambers in thus expended in flexing the diaphragm.

(5) Capacitance effect: The diaphragm and an adjacent stationary metal button (see Figure I-5) constitute a two-plate variable capacitor. Distention of the diaphragm away from the button decreases the capacitance.

When the chopper blocks the beams, as in B of Figure I-5, pressures in the two chambers equalize, and the diaphragm returns to the undistended condition. As the chopper alternately blocks and unblocks the beams, therefore, the diaphragm pulses, thus changing detector capacitance cyclically. The detector signal is passed through the electronic circuitry, where it is treated and sent to a meter and recorder.

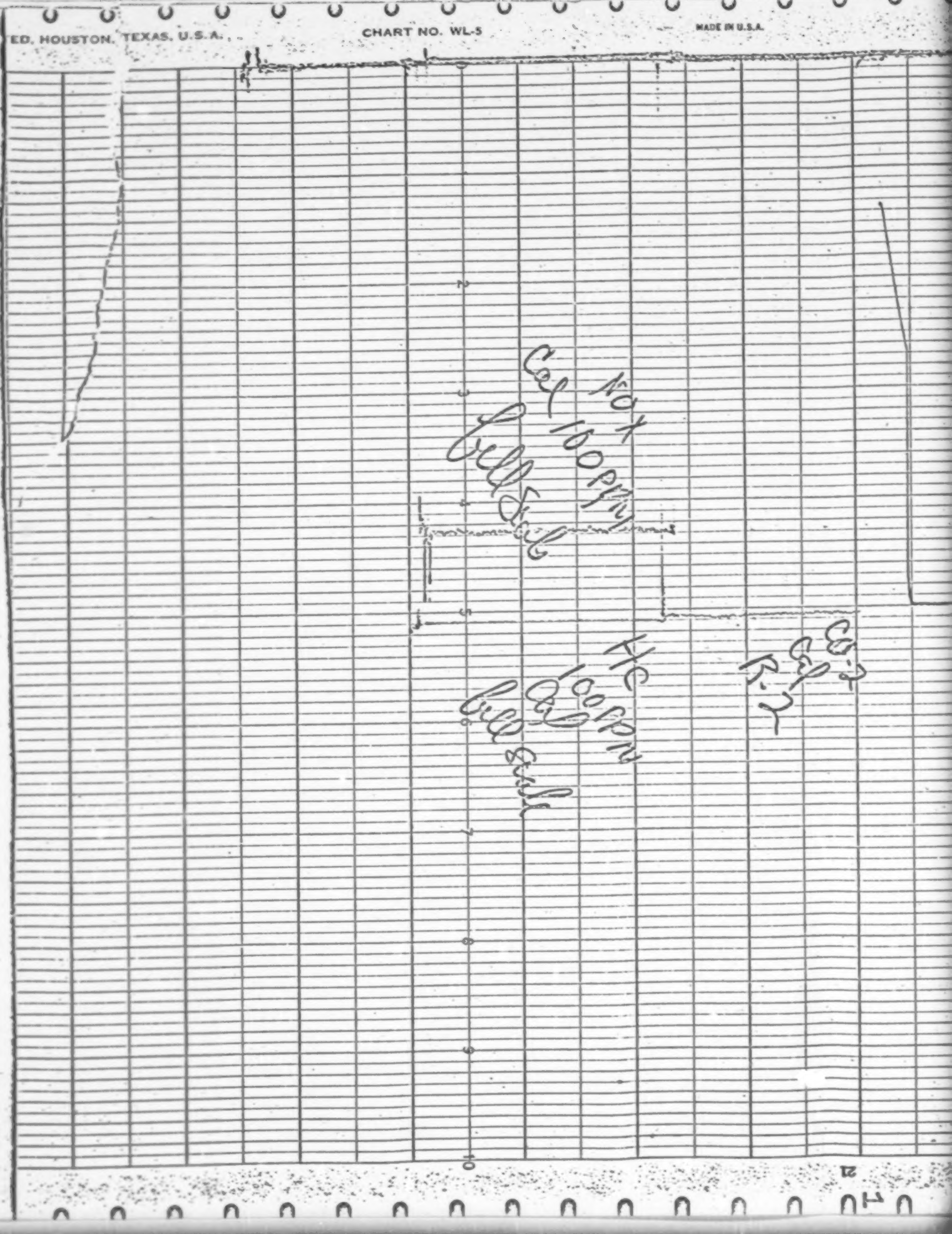
The meter reading is a function of the concentration of the component of interest in the sample stream. When the instrument is put into operation, it is adjusted so that a reading of zero or any desired arbitrary reading corresponds to a concentration of zero percent of the component of interest, while a fullscale reading corresponds to the highest concentration in the operating range covered. Each instrument is provided with a calibration curve for converting meter readings to concentrations.

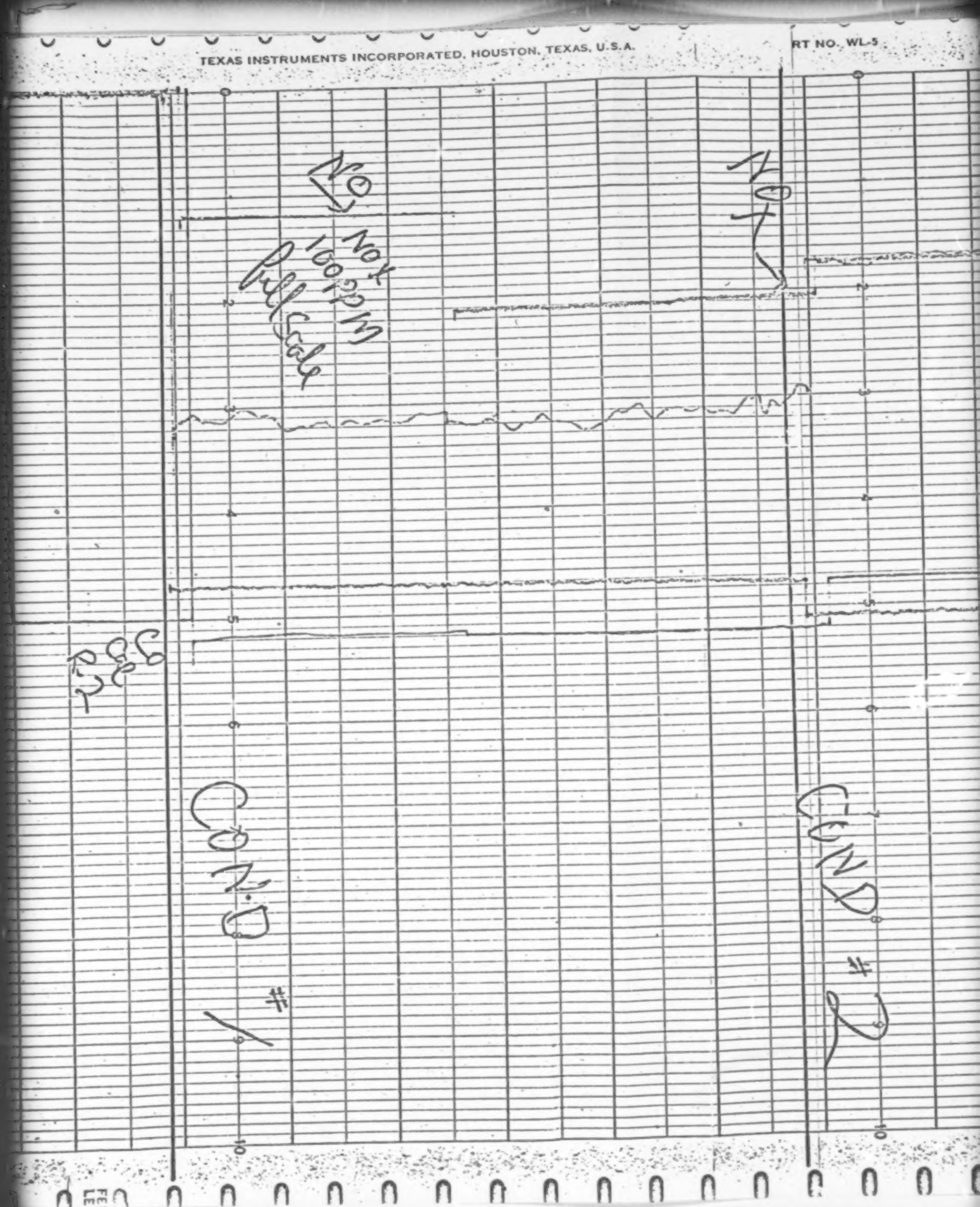
APPENDIX II

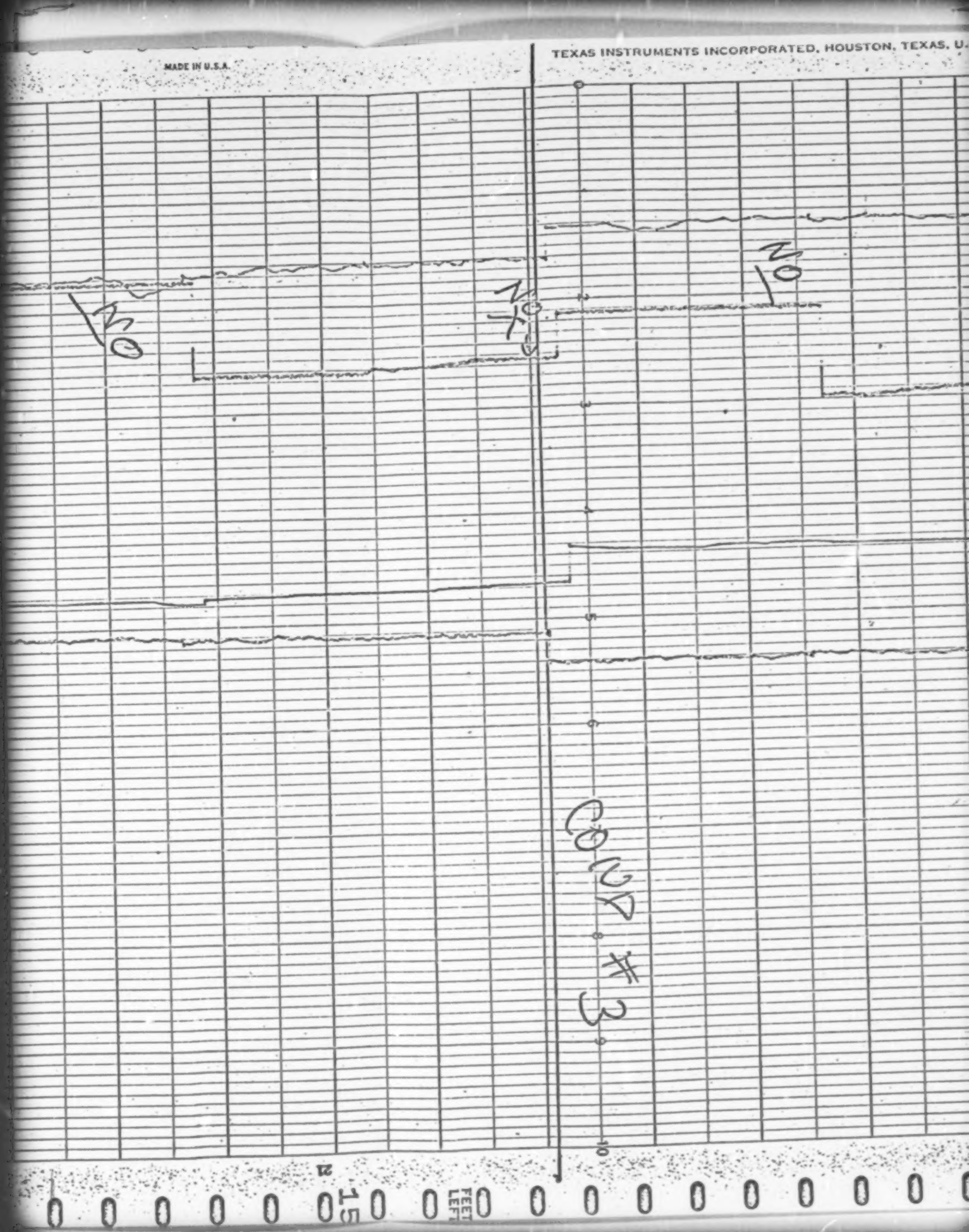
Representative Emissions Oscillograph Trace
(Attachment 1)

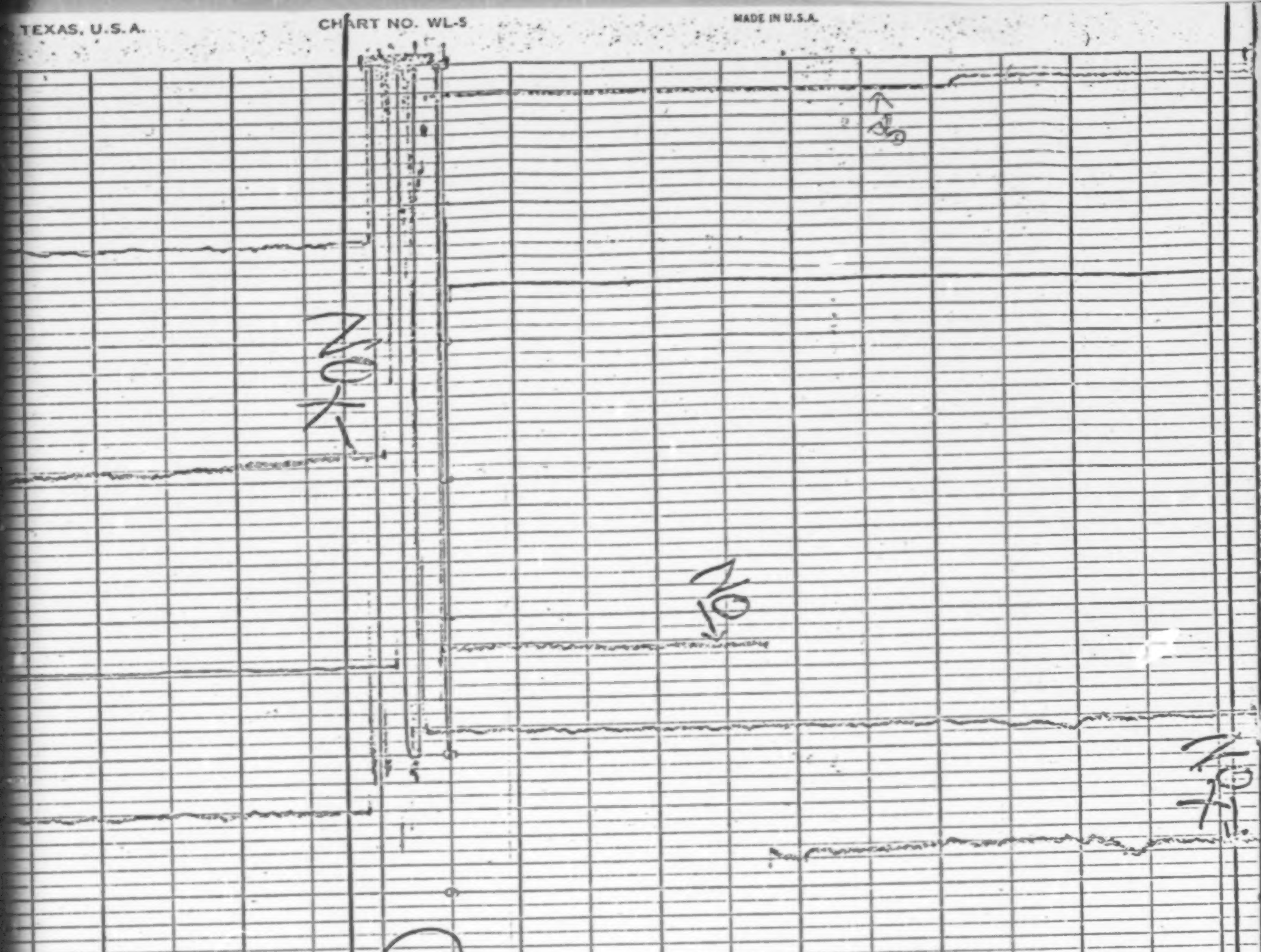
Laboratory Test Data Sheets
(Attachment 2)

Typical Emissions Data Presentation Format
(Attachment 3)


ED. HOUSTON, TEXAS, U.S.A.
CHART NO. WL-5
MADE IN U.S.A.
2
3
4
5
6
7
8
9
10
NOX
cal 100ppm
full scale
HC
100ppm
cal
full scale
CO-2
cal
R-2
12
1


TEXAS INSTRUMENTS INCORPORATED, HOUSTON, TEXAS, U.S.A.
RT NO. WL-5
0
2
3
4
5
6
7
8
9
10
NO NOx
1600 RPM
Full scale
NOx
COND #1
COND #2


MADE IN U.S.A.
TEXAS INSTRUMENTS INCORPORATED, HOUSTON, TEXAS, U.
NO
NOx
NO
COMP #3
0
10
15
FEET LEFT



TPE331-5-257M
11-6-75
LACC2

TEST DATE

ENGINE MODEL GTCP 85-98CK

ENGINE S/N P-36179

CONDITION 2

— 6-17-75 → | ← 6-18-75 →

DATA POINT		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
TIME		1345	1355	1405	1415	1435	1445	1455	1505	1520	1530	0845	0855	0910	0925	0945
BAROMETRIC PRESSURE	"HgA	28.47	28.47	28.47	28.47	28.47	28.47	28.47	28.47	28.47	28.47	28.44	28.44	28.44	28.44	28.44
ENGINE SPEED	RPM	41,600	41,440	41,120	41000	40,950	41,600	41,440	41,080	40,980	40,940	41,660	41,490	41,180	41,080	41,040
COMPRESSOR INLET TEMPERATURE	OF	18	21	21	19	21	21	20	18	18	20	18	19	19	19	19
COMPRESSOR INLET TOTAL PRESSURE	"HgA	28.47	28.47	28.47	28.47	28.47	28.47	28.47	28.47	28.47	28.47	28.44	28.44	28.44	28.44	28.44
FUEL FLOW	LB/HR	142	175	232	250	258	140	174	235	256	258	142	175	234	256	262
COMPRESSOR DISCHARGE PRESSURE	"HgG	127.0	125.0	122.5	114.2	117.5	126.0	125.0	123.5	114.2	117.3	128.0	126.0	124.0	115.5	119.2
COMPRESSOR DISCHARGE TEMPERATURE	OF	362	368	376	335	339	364	366	372	332	338	362	367	375	334	338
EXHAUST GAS TEMPERATURE	OF	467	571	775	881	861	464	567	780	879	860	462	565	774	864	863
EXHAUST GAS PRESSURE	"H2O	-12.5	-10.9	-7.5	-7.4	-7.3	-12.2	-10.7	-7.0	-7.5	-7.3	-12.3	-10.7	-7.0	-7.5	-7.3
ENGINE TORQUE	IN-LB	—	750	1880	—	435	—	750	1880	—	435	—	750	1880	—	435
ENGINE MASS FLOW AIR		364.26	334.40	310.51	409.04	400.09	361.27	334.40	314.99	406.06	406.05	364.26	334.40	314.99	412.03	404.56
BELLMOUTH STATIC ΔP	"H2O	12.055	10.800	8.773	15.646	14.925	11.989	10.758	8.949	15.657	14.936	12.205	10.884	9.026	15.770	15.217
BELLMOUTH TOTAL	"HgA	29.07	29.07	28.97	29.27	29.22	29.10	29.00	28.95	29.22	29.17	29.100	29.04	28.97	29.16	29.22
BELLMOUTH INLET TEMPERATURE	OF	18	21	21	19	21	22	20	18	18	20	18	19	19	19	19
BLEED AIR TEMPERATURE	OF	—	—	—	355	358	—	—	—	352	358	—	—	—	355	357
BLEED AIR PRESSURE	"HgG	—	—	—	111.5	115.2	—	—	—	112.0	114.8	—	—	—	113.2	116.5
ENGINE BLEED FLOW AIR		—	—	—			—	—	—			—	—	—		
BLEED ORIFICE PRESSURE	"HgG	—	—	—	100.7	107.9	—	—	—	101.0	106.5	—	—	—	101.5	108.2
BLEED ORIFICE ΔP	"H2O	—	—	—	24.0	17.0	—	—	—	24.0	17.0	—	—	—	24.0	17
BLEED ORIFICE TEMPERATURE	OF	—	—	—	333	339	—	—	—	332	335	—	—	—	332	334
WATER FLOW	GPH	3.4	3.1	2.9	3.8	3.7	3.4	3.1	2.9	3.8	3.7	3.4	3.1	2.9	3.8	3.7
SAMPLE LINE TEMPERATURE	OF	248	291	327	372	389	390	340	340	375	395	316	313	346	370	383
" " "	"	279	278	280	285	292	297	292	289	290	292	276	274	275	278	282
" " "	"	291	292	294	297	295	298	299	298	298	293	280	284	282	285	292
" " "	"	292	291	291	283	280	282	292	292	280	277	251	256	256	257	259

TEST CELL AECC-2
TEST OPERATORS STEWART-PILOT
WHITTEN-CO-PILOT
ENGINE FUEL TYPE JP4 REG

FLOW ROTOMETER NO. AR-265
WATER FLOWMETER NO. AR-323 -326
COMBUSTOR P/N —

ALTITUDE EQUIPMENT DIVISION		
CALCULATED	GS	5/75
RECORDED		
DRAWN		
CHECKED		
APPROVED		

GTCP85-98CK AMBIENT
EFFECTS PROGRAM

AiResearch Manufacturing Company of Arizona

TC 2

PX2588

AIRESEARCH MANUFACTURING COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

EXHAUST EMISSION DATA E-18

MATERIALS ENGINEERING

Test No. 3207-24618-01-0103
Date 6-17-75
Operator F H Barrand
Type of Engine APU GTCP
Model No. 85-98CQ
Engine S/N 3179

Data Point	Time	Line Temperature °F 1	2	3	4	5	6	7	8	9	10	CO$_2$ Zero	CO$_2$ Gain	CO Zero	CO Gain	HC Zero	HC Gain	NO$_x$ Gain	Remarks
CAL	1:30											667	056	450	297	897	782	334	WET
16	1:35	122	130	117	127	128	127	152	216	342	323	"	"	"	"	"	"	"	
17	1:45	122	129	119	130	127	134	150	214	327	316	"	"	"	"	"	"	"	
18	1:55	122	129	119	130	130	172	151	212	306	317	"	"	"	"	"	"	"	
19	2:10	123	130	120	130	130	172	151	302	332	312	"	"	"	"	"	"	"	
20	2:26	123	131	120	131	131	162	128	302	341	305	"	"	"	"	"	"	"	
CAL	2:30											"	"	"	"	858	785	"	
21	2:36	123	130	120	131	130	173	138	271	304	305	"	"	"	"	"	"	"	
22	2:47	123	131	121	132	130	171	136	217	303	299	"	"	"	"	"	"	"	
23	2:58	124	131	121	133	130	118	135	277	335	219	"	"	"	"	"	"	"	
24	3:10	124	131	121	132	130	168	131	215	335	298	"	"	"	"	"	"	"	
25	3:21	126	131	171	132	[illegible]	165	142	217	332	303	"	"	"	"	"	"	"	
CAL	3:25											"	"	"	"	"	"	"	
6-18-75																			
CAL	8:30											653	058	456	295	898	793	340	
26	8:35	122	126	123	123	121	140	135	218	331	298	"	"	"	"	"	"	"	
27	8:48	123	127	123	133	122	141	133	300	337	300	"	"	"	"	"	"	"	
28	9:02	125	128	124	123	123	137	138	302	321	325								
29	9:14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]								
30	9:36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]								
CAL	9:40																		

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```
ENGINE MFR.: AIRESEARCH      TEST FACILITY: PHX C-105       INSTR. DESCRIP.: REPORT GT-8747R          CALC. DATE: 3-19-73
MODEL NO.: TPE331-5-251     S/N:  P06160        ENGINE TYPE (CLASS):  T1              CALC. I.D.: G106
RATED TAKE-OFF POWER:    715.0 SHP  AT SEA LEVEL STANDARD DAY CONDITIONS
FUEL: ASTM D1655-ANT. JET A-1  ATOMIC H/C RATIO:   1.928 LHV:      18470. BTU/LB.      ADDITIVES:     NONE

******** EXHAUST EMISSIONS PER EPA CYCLE OF WORK OUTPUT ** CODE OF FEDERAL REGULATIONS TITLE 40 PART 87  12 DEC 1972  ********
                    HYDROCARBONS (CH AS CH4)            1.922 LB. POLLUTANT PER 1000 HP.-HR. PER CYCLE
                    CARBON MONOXIDE (CO)               17.433 LB. POLLUTANT PER 1000 HP.-HR. PER CYCLE
                    OXIDES OF NITROGEN (NOX AS NO2)    17.821 LB. POLLUTANT PER 1000 HP.-HR. PER CYCLE
                    SMOKE                              18.5    SMOKE NUMBER, MAXIMUM AT CLIMB-OUT  MODE

***************************************************** ENGINE DESCRIPTION *******************************************************
COMBUSTOR TYPE: REVERSE-FLOW ANNULAR    P/N:  869082-4  SURFACE/VOLUME: 1.260 SQ IN/CU IN     FUEL INJ. TYPE:  SIMPLEX
ENGINE TOTAL SERVICE:  NEW      HR.   TIME SINCE ENGINE OVERHAUL:   NA      HR.
ENGINE ASSEMBLY AND MAINTENANCE INFORMATION:

AIRCRAFT INSTALLATION *** MFR.:  NORTH AMERICAN              MODEL NO.:
                       USER: AEROCOMMANDER         ENGINE INSTALLATION POSITION:

*****************************************************OPERATIONAL TEST DATA SUMMARY *********************************************
GASEOUS EMISSION TEST NO.:  G106          DATE:  3-19-73              TIME:  11:00                  BARO PRESS.:  28.670 IN. HGA.
AMBIENT AIR TEMP.:  72.00 DEG. F          RELATIVE HUMIDITY:  33.00 PERCENT          SPECIFIC HUMIDITY:   0.0057 LB. H2O/LB. DRY AIR
AMBIENT AIR QUALITY     HYDROCARBONS (HC):        PPMC       CARBON MONOXIDE (CO):        PPMV    OXIDES OF NITROGEN (NOX):        PPMV
SAMPLE LINE *** TEMP.:  300.00 DEG. F.      FLOWRATE:    0.00 LITERS/MIN.      TRANSPORT TIME:    2.00 SEC.      LENGTH:   20.00 FT.

**************************************************** COMPUTED EMISSIONS ******************************************************
TEST CONDITION                                            1          2          3          4          5          6          7
POWER SETTING, PERCENT RATED TAKE-OFF                  99.7       89.8       74.9       50.0       30.2       15.0        5.1
POWER SETTING,  HP. (OR LB. THRUST)                   713.2      641.8      535.2      357.2      215.8      107.3       36.3
N1 SPEED, RPM                                      41730.00   41730.00   41730.00   41730.00   41730.00   41730.00   41370.00
FUEL FLOW (MEAS.) LB./HR.                             424.0      396.0      355.0      290.0      236.0      207.0      185.0
ENGINE CORE INLET AIR FLOW (MAP)                        0.0        0.0        0.0        0.0        0.0        0.0        0.0
ENGINE PRESSURE RATIO                                 -0.00      -0.00      -0.00      -0.00      -0.00      -0.00      -0.00
COMPRESSOR INLET TEMP., DEG. F.                        59.0       59.0       59.0       59.0       59.0       59.0       59.0
COMPRESSOR DISCHARGE AIR PRESSURE, PSIA              146.71     145.72     142.78     138.11     135.41     132.46     130.01
COMPRESSOR DISCHARGE AIR TEMP., DEG. F                680.0      679.0      674.0      668.0      660.0      658.0      655.0
COMPRESSOR BLEED AIR FLOW (MEAS.)                       0.0        0.0        0.0        0.0        0.0        0.0        0.0
TURBINE INLET GAS TEMP., DEG. F                        -0.0       -0.0       -0.0       -0.0       -0.0       -0.0       -0.0
TURBINE INTERSTAGE GAS TEMP., DEG. F                 1450.0     1385.0     1300.0     1165.0     1060.0      985.0      940.0
EXHAUST GAS STATIC PRESSURE, PSIA                     13.95      13.94      13.93      13.93      13.94      13.94      13.96
EXHAUST GAS TOTAL PRESSURE, PSIA                      14.09      14.09      14.08      14.08      14.08      14.08      14.08
ENGINE EXHAUST GAS TEMP., DEG. F                       -0.0       -0.0       -0.0       -0.0       -0.0       -0.0       -0.0
EMISSION CONCENTRATION, WET ANALYSIS
     HYDROCARBON (HC AS CH4), PPMC                    2.704      3.004      5.407      6.609      7.510      9.012     20.727
     CARBON MONOXIDE (CO), PPMV                      12.971     15.338     31.146     55.610     68.990     80.856     93.623
     TOTAL OXIDES OF NITROGEN (NOX), PPMV           116.157    106.143     92.624     76.101     60.480     49.065     42.056
     CARBON DIOXIDE (CO2), PERCENT BY VOL.            3.326      3.069      2.731      2.208      1.877      1.608      1.439
     NITRIC OXIDE (NO), PPMV                        110.149     97.631     80.107     56.575     42.356     30.841     21.028
EMISSION INDEX, LB. POLLUTANT/1000 LB. FUEL
     HYDROCARBONS (HC AS CH4)                          .033       .112       .227       .342       .457       .640      1.640
     CARBON MONOXIDE (CO)                              .783      1.003      2.288      5.041      7.347     10.040     12.962
     TOTAL OXIDES OF NITROGEN (NOX AS NO2)           11.517     11.398     11.170     11.333     10.579     10.008      9.564
EMISSION RATE, LB. POLLUTANT/HR.
     HYDROCARBONS (HC AS CH4)                          .040       .044       .081       .099       .108       .132       .303
     CARBON MONOXIDE (CO)                              .316       .397       .812      1.462      1.734      2.078      2.398
     TOTAL OXIDES OF NITROGEN (NOX AS NO2)            4.961      4.514      3.945      3.286      2.497      2.072      1.769
COMBUSTION EFFICIENCY, PERCENT (EMISSIONS)            99.97      99.97      99.93      99.85      99.79      99.71      99.55
[illegible]                                            .016       .015  [illegible]     .011       .009       .008       .007
```

Typical Format for Emissions Data Presentation.

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APPENDIX III

Attached Drawings:

Emissions Sampling Probe - SKP32566

TPE331 Combustor Rig Assembly - SKP16260

PART NUMBER	A	B	C
SKP32566-1	1.95 1.90	3.37 3.32	4.35 4.30
SKP32566-2	1.65 1.60	2.86 2.81	3.69 3.64

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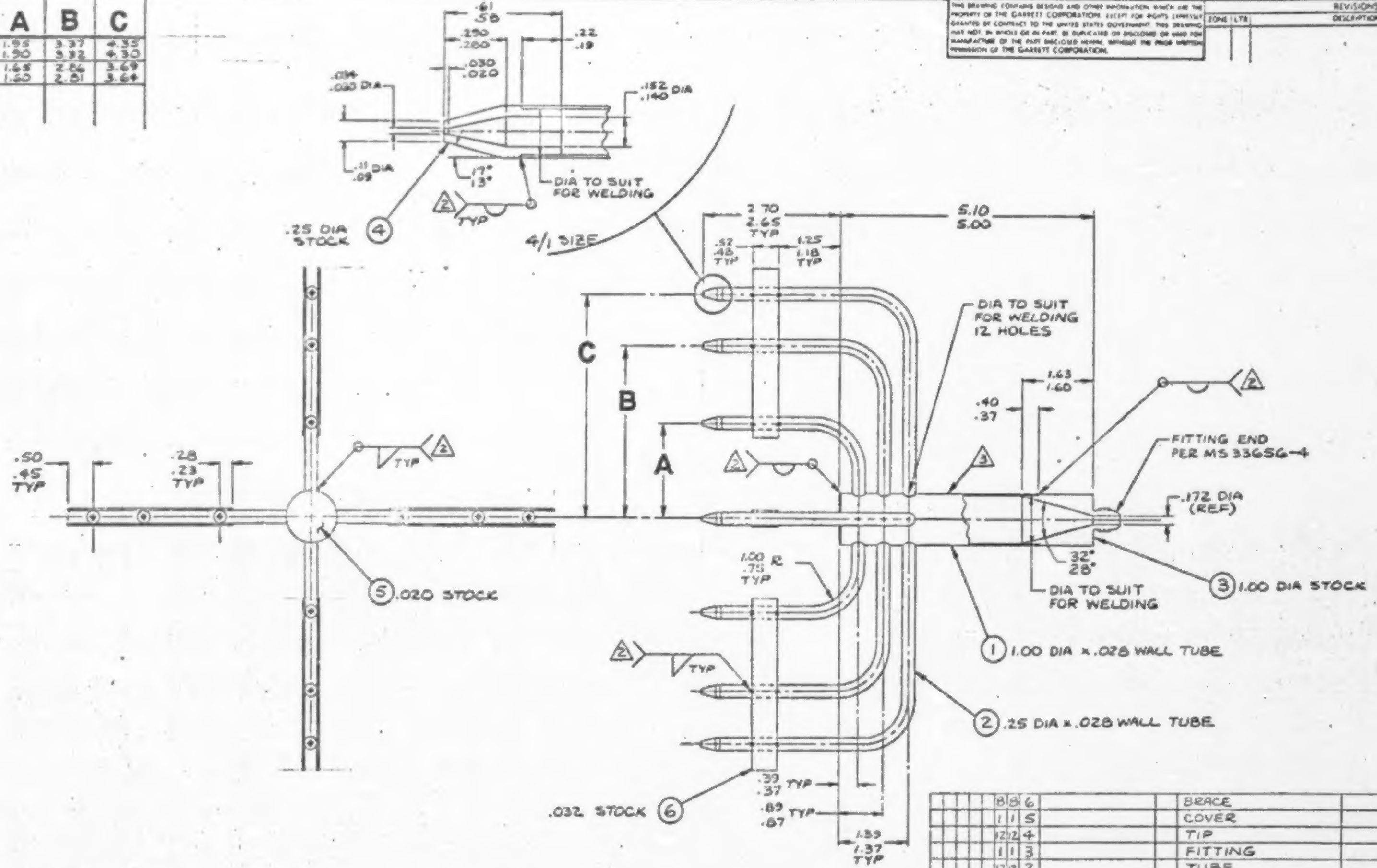
REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED


.61
.56
.250
.280
.22
.19
.030
.020
.034
.030 DIA
.152 DIA
.140
.11 DIA
.09
17°
13°
DIA TO SUIT FOR WELDING
2
TYP
.25 DIA STOCK
4
4/1 SIZE
2.70
2.65
TYP
.52
.48
TYP
1.25
1.18
TYP
5.10
5.00
DIA TO SUIT FOR WELDING 12 HOLES
1.63
1.60
.40
.37
C
B
A
.50
.45
TYP
.28
.23
TYP
TYP
2
3
FITTING END PER MS 33656-4
.172 DIA (REF)
32°
28°
DIA TO SUIT FOR WELDING
3
1.00 DIA STOCK
5
.020 STOCK
1.00
.75 R
TYP
1
1.00 DIA x .028 WALL TUBE
2
.25 DIA x .028 WALL TUBE
.39
.37 TYP
.89
.87 TYP
1.39
1.37
TYP
.032 STOCK
6

REDUCED PRINT

QUANTITY REQD		FIND NO	PART NO OR IDENTIFYING NO	SYM	NOMENCLATURE OR DESCRIPTION	CODE IDENT	MATERIAL AND SPECIFICATION
8	8	6			BRACE		CRES-316 QQ-S-763
1	1	5			COVER		
12	12	4			TIP		
1	1	3			FITTING		
12	12	2			TUBE		
1	1	1			TUBE		CRES-347-MIL-T-8606
-2	-1	← PART NUMBER					

PARTS LIST

△3 PART NO. PER AIRESEARCH MC 5014, CL II.

△2 WELD PER AIRESEARCH WBS 5018.

1. SHALL CONFORM TO AIRESEARCH SC6002 MACHINED FEATURES

REQD	NEXT ASSY	USED ON
HEAT TREATMENT		PROCESS
HARDNESS AND SPEC		NAME AND SPEC

CONTRACT NO

DFT 2-4-75
CHK
MFG
MATL
STRESS
AERO
APPD 2-6-75
DESIGN ACTIVITY APPD
OTHER ACTIVITY APPD 2-6-75

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DWG TITLE

PROBE,
EMISSIONS SAMPLING

SIZE D
CODE IDENT NO 99193
DWG NO SKP 32566
SCALE 1/1 & AS NOTED
WT
SHEET OF

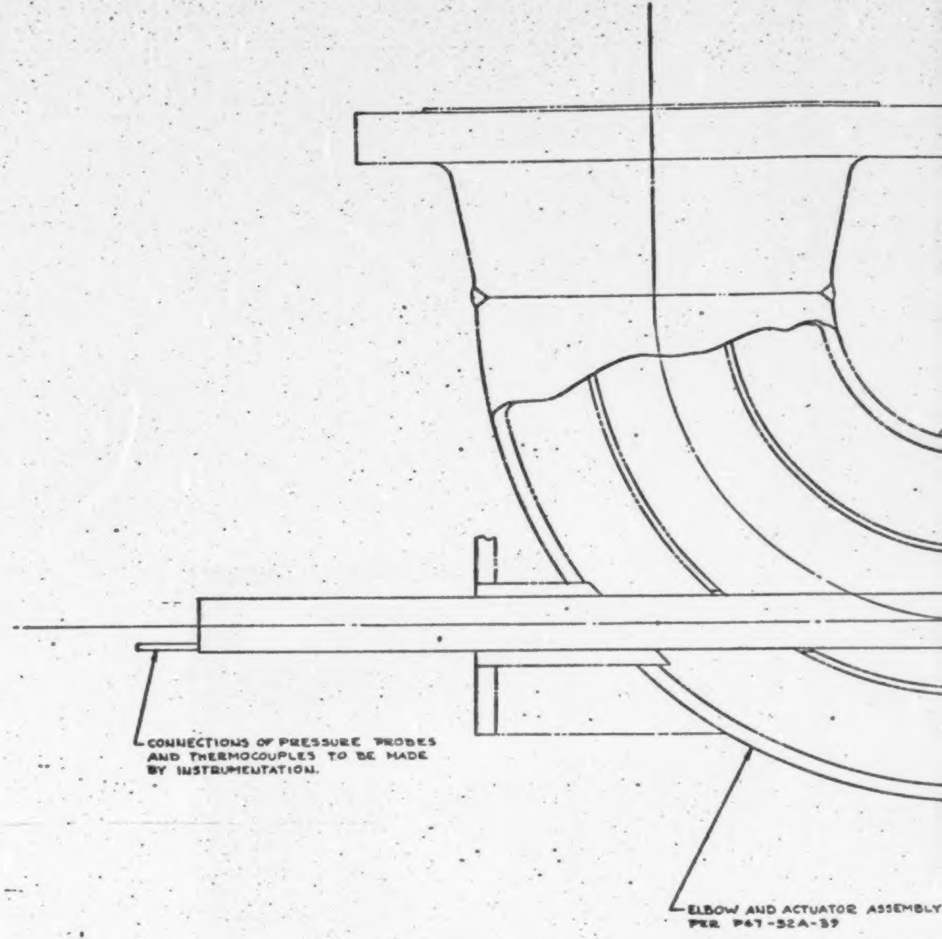
SKP32566

MICROFILMED

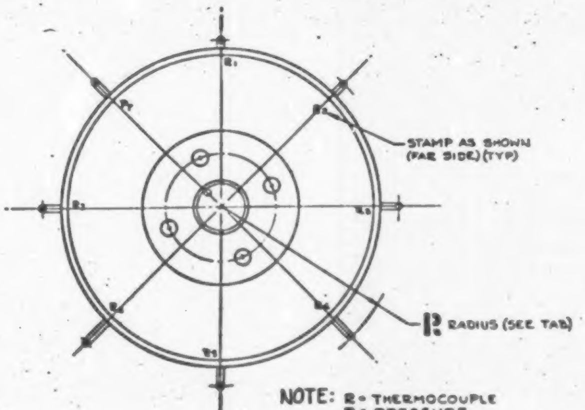
20 19 18 17 16

PART NUMBER
SKP16260-1

H
G
F
E
D
C
B
A

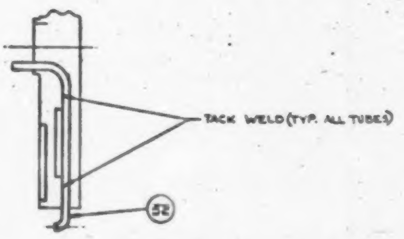

CONNECTIONS OF PRESSURE PROBES AND THERMOCOUPLES TO BE MADE BY INSTRUMENTATION.
ELBOW AND ACTUATOR ASSEMBLY
PER P67-32A-39

PROBE	R RADIUS
R1	3.10
R2	3.20
R3	3.30
R4	3.40
R5	3.30
R6	3.30
R7	3.30
P7	3.30

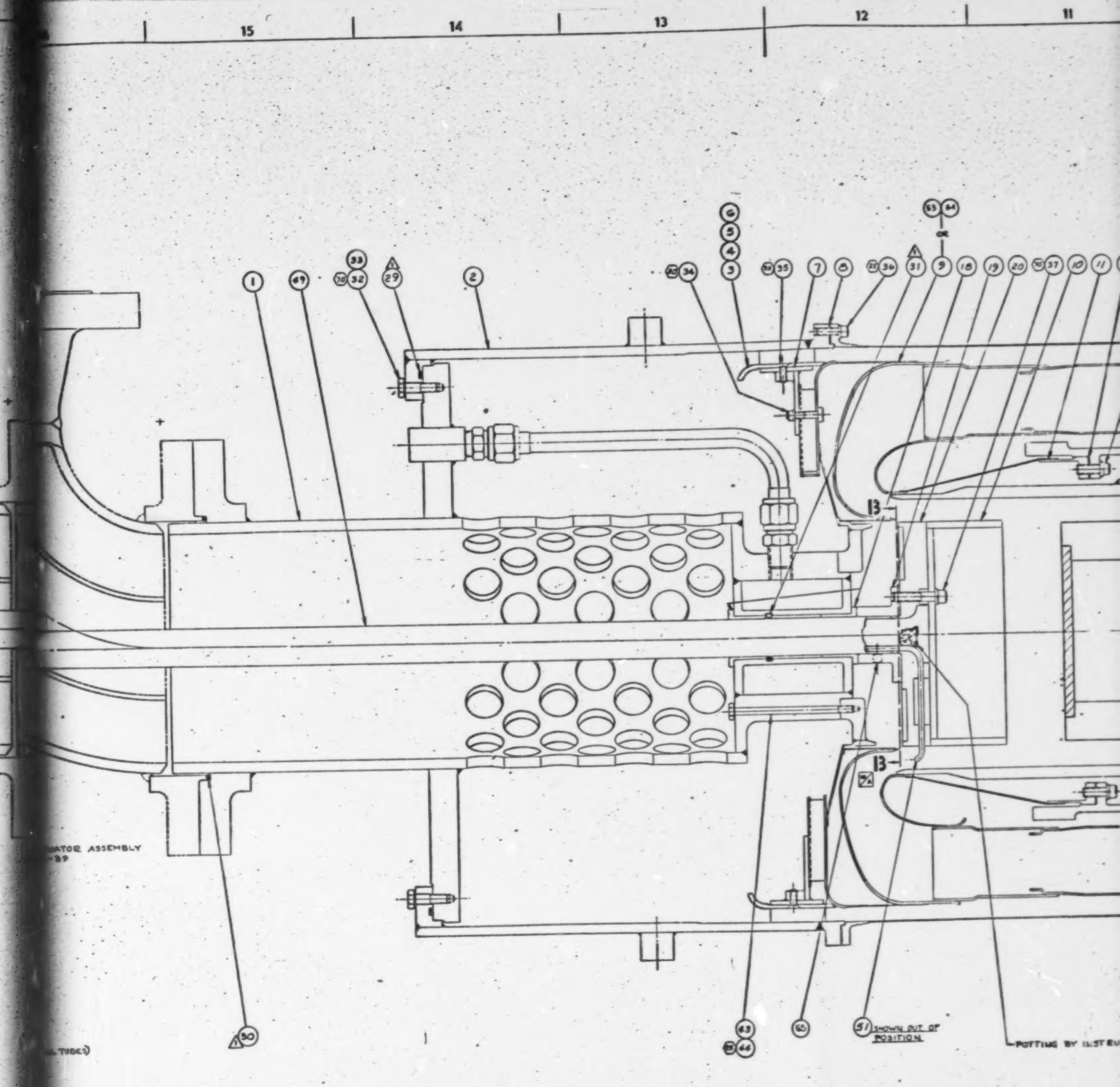

R1
P7
R2
R3
R4
R5
R6
R7
STAMP AS SHOWN (FAR SIDE) (TYP)
R RADIUS (SEE TAB)

NOTE: R = THERMOCOUPLE
P = PRESSURE

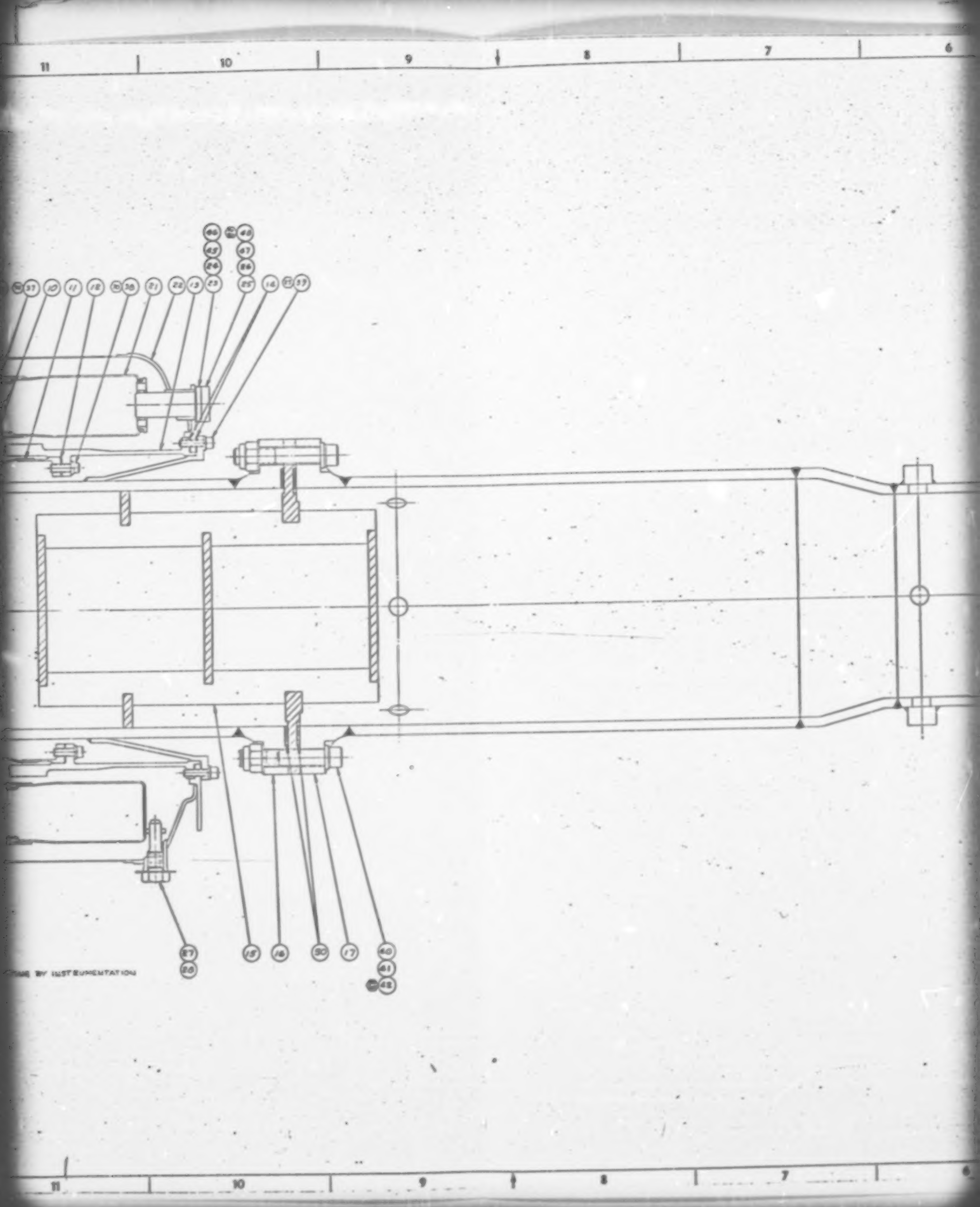
SECTION B-B ½

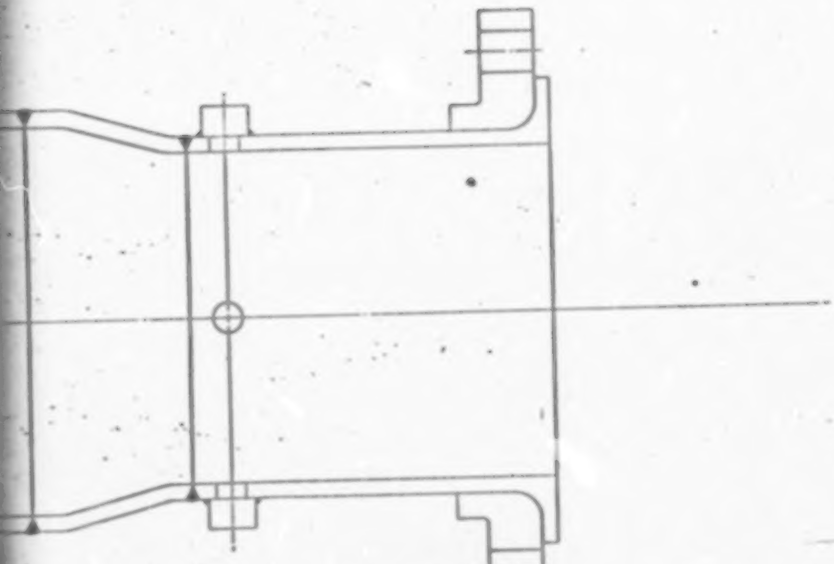

TACK WELD (TYP. ALL TUBES)
52

20 19 18 17 16


70 32
20 34
30 35
25 36
53 54
OR
70 37
ATOR ASSEMBLY
-39
L TUBES)
25 44
51 SHOWN OUT OF POSITION
POTTING BY INSTRU

SKP16260 -


BY INSTRUMENTATION



REQ'D	ITEM NO.	PART NO.	CODE	DESCRIPTION
2	55	MS9016-15		SET SCREW
1	54	SKP16267-1		SPACER
1	53	SKP16268-1		LINER ASSEMBLY
[illegible]	52			1/8 DIA. MGO
[illegible]	51			TUBE 1/8 DIA x .035
[illegible]	50			SPIRAL WOUND
1	49			TUBE (OD x 1/8)
[illegible]	48	MS21043-6		NUT
[illegible]	47	MS9490-10		BOLT
[illegible]	46	472-94-9301	△	COMPOUND
[illegible]	45	S6037-4P3		PACKING
[illegible]	44	AN3C31A		BOLT
[illegible]	43	AN960C10L		WASHER
[illegible]	42	MS21042L3		NUT
[illegible]	41	AN960C816L		WASHER
[illegible]	40	MS21-284-24		BOLT
[illegible]	39	MS21-279-10		BOLT
[illegible]	38	MS21-280-24		BOLT
[illegible]	37	MS21-280-6		BOLT
[illegible]	36	MS21-279-15		BOLT
[illegible]	35	[illegible]		SCREW
[illegible]	34	MS21043-3		NUT
[illegible]	33	AN960C10L		WASHER
[illegible]	32	AN4C6A		BOLT
1	31	AN6227B-19		PACKING
1	30	S6117M-39		PACKING
1	29	S6990-20		PACKING
[illegible]	28	692481		COMBUSTOR
[illegible]	27	696331		LOCKING PLATE
1	26	965219-2		MANIFOLD
1	25	965219-1		MANIFOLD
[illegible]	24	692476		GASKET
[illegible]	23	369620		NOZZLE ASS
1	22	SKP16199-1		PLENUM ASSEM
1	21	847696-1		CHAMBER ASS
1	20	MS21-324-41		HOLDER
1	19	MS21-324-46		ADAPTER
2	18	AN-324-26		BUSHING
1	17	SKP16178-1		DUCT
1	16	SKP16265-1		DUCT ASSEMB
1	15	SKP16179-1		BAFFLE
2	14	SKP16267-3		GASKET
1	13	SKP16262-1		TRANSITION
1	12	SKP16267-1		GASKET
1	11	SKP16171-1		LINER, INNER
1	10	SKP15191		COVER
1	9	SKP16266-1		LINER ASSEM
1	8	SKP16267-2		GASKET
1	7	SKP16264-1		LINER, GUIDE
[illegible]	6	SKP16259-4		GUIDE VANES
[illegible]	5	SKP16259-3		GUIDE VANES
[illegible]	4	SKP16259-2		GUIDE VANES
[illegible]	3	SKP16263-1		GUIDE VANES
1	2	SKP16261-1		SHROUD
1	1	SKP17303		AIR INLET

ASSY LIST

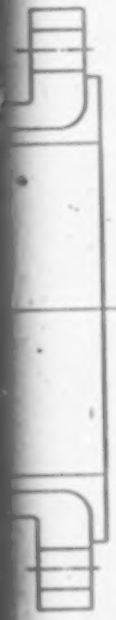
		SIGNATURES
FINAL		
NEXT ASSY	USED ON	

△ VENDOR ITEM: SEE APPLICABLE SPECIFICATION OR SOURCE CONTROL DRAWING.

△ TORQUE VALUES SHOWN THUS ○ OR AS SPECIFIED IN AIRESEARCH SPEC AP-249, TABLE 1, ARE FOR BOLT LOADING. THE LOWER VALUE IS TO BE USED WHEN THE NUT IS TORQUED AND THE BOLT HELD STATIONARY. THE HIGHER VALUE WHEN THE BOLT IS TORQUED AND THE NUT HELD STATIONARY. FRICTIONAL TORQUES DEVELOPED FROM SELF-LOCKING FEATURES MUST BE ADDED TO EACH VALUE AT TIME OF ASSEMBLY.

△ USE HIGH TEMPERATURE GREASE AT ASSEMBLY.

SKP16260



2	55	MS51976-?		SET SCREW	
1	54	SKP16307-1		SPACER	
1	53	SKP16318-1		LINER ASSEMBLY	
	52			1/8 DIA. MGO	CHROMEL-ALUMEL
	51			TUBE 1/8 DIA. x .035 WALL	CRES 316
	50			SPIRAL WOUND GASKET	FLEXITALLIC GASKET CO.
1	49			TUBE-.500 x ...	CRES 316
	48	MS21043-4		NUT	
	47	[illegible]		BOLT	
	46	[illegible]	▲	COMPOUND	
	45	[illegible]		PACKING	
	44	[illegible]		BOLT	
	43	[illegible]		WASHER	
	42	[illegible]		NUT	
	41	[illegible]		WASHER	
	40	[illegible]		BOLT	
	39	[illegible]		BOLT	
	38	[illegible]		BOLT	
	37	[illegible]		BOLT	
	36	[illegible]		BOLT	
	35	[illegible]		SCREW	
	34	MS21043-3		NUT	
	33	[illegible]		WASHER	
	32	[illegible]		BOLT	
1	31	[illegible]		PACKING	
1	30	[illegible]		PACKING	
1	29	[illegible]		PACKING	
	28	672481		COMBUSTOR BOLT	
	27	674331		LOCKING PLATE	
1	26	843219-2		MANIFOLD	
1	25	843219-1		MANIFOLD	
	24	672476		GASKET	
	23	367420		NOZZLE ASSEMBLY	
1	22	[illegible]		PLENUM ASSEMBLY	
1	21	[illegible]		CHAMBER ASSEMBLY	
1	20	[illegible]		HOLDER	
1	19	[illegible]		ADAPTER	
	18	[illegible]		BUSHING	
1	17	[illegible]		DUCT	
1	16	[illegible]		DUCT ASSEMBLY	
1	15	[illegible]		BAFFLE	
	14	[illegible]		GASKET	
1	13	[illegible]		TRANSITION SECTION	
1	12	[illegible]		GASKET	
1	11	[illegible]		LINER, INNER	
1	10	[illegible]		COVER	
1	9	[illegible]		LINER ASSEMBLY	
1	8	[illegible]		GASKET	
1	7	[illegible]		LINER, GUIDE VANES	
	6	[illegible]		GUIDE VANES	
	5	[illegible]		GUIDE VANES	
	4	[illegible]		GUIDE VANES	
	3	[illegible]		GUIDE VANES	
1	2	[illegible]		SHROUD	
1	1	[illegible]		AIR INLET	

LIST OF MATERIAL

▲ VENDOR ITEM: SEE APPLICABLE SPECIFICATION OR SOURCE CONTROL DRAWING.

▲ [illegible]

▲ USE HIGH TEMPERATURE GREASE AT ASSEMBLY.

AIRESEARCH MANUFACTURING COMPANY

RIG ASSEMBLY,
COMBUSTOR TEST

J 99193 SKP1626?

SCALE FULL

SKP16260

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